

WORLD METEOROLOGICAL ORGANIZATION

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# TECHNICAL REGULATIONS

VOLUME III

## Hydrology

2006 edition



Basic Documents No. 2

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NOTE

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2006 edition

## TABLE FOR NOTING SUPPLEMENTS

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#### EDITORIAL NOTE

The following typographical practice has been followed:

*Standard* practices and procedures have been printed in semi-bold roman

*Recommended* practices and procedures have been printed in light face roman. (Definitions appear in bigger type.)

*Notes* have been printed in smaller type, light face roman, and preceded by the indication: NOTE.

## INTRODUCTION

1. The WMO *Technical Regulations* (WMO-No. 49) are presented in three volumes:

Volume I — General meteorological standards and recommended practices

Volume II — Meteorological service for international air navigation

Volume III — Hydrology.

### Purpose of the Technical Regulations

2. The Technical Regulations of the World Meteorological Organization are determined by Congress in accordance with Article 8(d) of the Convention.

3. These Regulations are designed:

- (a) To facilitate cooperation in meteorology and hydrology between Members;
- (b) To meet, in the most effective manner, specific needs in the various fields of application of meteorology and hydrology in the international sphere; and
- (c) To ensure adequate uniformity and standardization in the practices and procedures employed in achieving (a) and (b) above.

### Types of Regulations and notes

4. The Technical Regulations comprise *standard* practices and procedures and *recommended* practices and procedures.

5. The definitions of these two types of Regulations are as follows:

The *standard* practices and procedures:

- (a) Shall be the practices and procedures which it is *necessary* that Members follow or implement; and therefore
- (b) Shall have the status of requirements in a technical resolution in respect of which Article 9(b) of the Convention is applicable; and
- (c) Shall invariably be distinguished by the use of the term *shall* in the English text, and by suitable equivalent terms in the Arabic, Chinese, French, Spanish and Russian texts.

The *recommended* practices and procedures:

- (a) Shall be the practices and procedures which it is *desirable* that Members follow or implement; and therefore
- (b) Shall have the status of recommendations to Members, to which Article 9(b) of the Convention shall not be applied;
- (c) Shall be distinguished by the use of the term *should* in the English text (except where otherwise provided by decision of Congress) and by suitable equivalent terms in the Arabic, Chinese, French, Russian and Spanish texts.

6. In accordance with the above definitions, Members shall do their utmost to implement the *standard* practices and procedures. In accordance with Article 9(b) of the Convention and in conformity with the provisions of Regulation 127 of the General Regulations, Members shall formally notify the Secretary-General, in writing, of their intention to apply the *standard* practices and procedures of the Technical Regulations, except those for which they have lodged a specific deviation. Members shall also inform the Secretary-General, at least three months in advance, of any change in the degree of their implementation of a *standard practice or procedure* as previously notified and the effective date of the change.

7. Members are urged to comply with *recommended* practices and procedures, but it is not necessary to notify the Secretary-General of non-observance except with respect to those contained in subsection C.3.1.

8. In order to clarify the status of the various Regulations, the standard practices and procedures are distinguished from the recommended practices and procedures by a difference in typographical practice, as indicated in the editorial note.

9. Certain notes (preceded by the indication NOTE) are included in the Technical Regulations for explanatory purposes; they may, for instance, refer to relevant WMO guides and WMO publications of factual information. These notes do not have the status of Technical Regulations. (The WMO guides describe practices, procedures and specifications which Members are *invited* to follow or implement in establishing and conducting their arrangements in compliance with the Technical Regulations and in developing meteorological and hydrological services in their respective countries.)

### Status of annexes and appendices

10. WMO publications (other than the Technical Regulations (Volumes I to III)) which contain regulatory

material having the status of the Technical Regulations are *annexes* to the Technical Regulations. These annexes, normally also called *manuals*, are established by decision of Congress and are intended to facilitate the application of Technical Regulations to specific fields. In principle, annexes may contain both standard and recommended practices and procedures.

11. Texts called *appendices* appearing in the Technical Regulations or in an annex to the Technical Regulations have the same status as the Regulations to which they refer.

### Updating of the Technical Regulations and their annexes

12. The Technical Regulations are updated, as necessary, in the light of developments in meteorology and hydrology and meteorological and hydrological techniques and in the applications of meteorology. Certain principles previously agreed upon by Congress and applied in the selection of material for inclusion in the Technical Regulations are reproduced below. These principles provide guidance for constituent bodies, in particular technical commissions, when dealing with matters pertaining to the Technical Regulations:

- (a) Technical commissions should not recommend that a Regulation be a *standard* practice unless it is supported by a strong majority;
- (b) Technical Regulations should contain appropriate instructions to Members regarding implementation of the provision in question;
- (c) No major changes should be made in the Technical Regulations without consulting the appropriate technical commissions;
- (d) Any amendments proposed to these Technical Regulations submitted by Members or by constituent bodies should be communicated to all Members at least three months before they are submitted to Congress.

13. Amendments to the Technical Regulations — as a rule — are approved by Congress.

14. If a recommendation for an amendment is made by a session of the appropriate technical commission and if the new regulation needs to be implemented before the time of next Congress, the Executive Council may, on behalf of the Organization, approve the amendment in accordance with Article 14(c) of the Convention. Amendments to *annexes* to the Technical Regulations proposed by the appropriate technical commissions are normally approved by the Executive Council.

15. If a recommendation for an amendment is made by the appropriate technical commission and the implementation of the new regulation is urgent, the President of the Organization may, on behalf of the Executive Council, take action as provided by Regulation 9(5) of the General Regulations.

16. As far as the publication of updated material in WMO-No. 49 is concerned, new editions of Volumes I and III are normally issued after each session of Congress (i.e. four-yearly). The material in Volume II is prepared by the World Meteorological Organization and the International Civil Aviation Organization working in close cooperation, in accordance with the Working Arrangements agreed by these Organizations; this also applies to the issuing of new editions of Volume II. In the period between the publication of two subsequent editions, the Technical Regulations are kept up to date by means of supplements, as necessary.

### Technical Regulations for Hydrology

17. Volume III of the Technical Regulations presents recommended practices and procedures in hydrology. Some of the regulations contained in Volume I meet the requirements of hydrology. In such cases the relevant texts have been reproduced herein.

18. This volume includes an annex entitled Hydrological instruments and methods of observation.

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## DEFINITIONS

**Introductory note.** The following terms, when used in Volume III of the *Technical Regulations*, have the meanings given below. Some of these terms have already been defined in Volume I or in the *Manual on the Global Observing System* (WMO-No. 544), which constitutes Annex V to the WMO *Technical Regulations*, but it was considered desirable, for the convenience of the reader, to repeat the definitions in this volume. These terms are identified by an asterisk.

**Alarm level.** Water level (stage) at, or approaching, flood level which is considered to be dangerous and at which warnings should be commenced.

**\*Altitude.** The vertical distance of a level, a point, or an object considered as a point, measured from mean sea-level.

**Aquifer.** Porous water-bearing formation capable of yielding exploitable quantities of water.

**\*Automatic station.** A station at which instruments make and either transmit or record observations automatically, the conversion to code form, if required, being made either directly or at an editing station.

**Catchment area.** An area having a common outlet for its surface runoff.

**\*Climatological station.** A station from which climatological data are obtained.

**Climatological station for hydrological purposes.** A climatological station set up in a drainage basin specifically to augment the existing climatological network in order to meet hydrological requirements.

**\*Climatological station for specific purposes.** A climatological station established for the observation of a specific element or elements.

**Discharge.** The volume of water flowing through a cross-section in a unit time.

**Drainage basin.** (See *Catchment area*)

**Drainage flood.** A flood which results from rainwater ponding at or near the point where it falls because it is falling faster than the drainage system (natural or man-made) can carry it away.

**\*Elevation.** The vertical distance of a point or level on or affixed to the surface of the Earth, measured from mean sea level.

**Estuary.** That generally broad portion of a river near its outlet, upstream of which stages are a function of the discharge from upstream, downstream of which they are a function of tides and surges of the water body into which it flows.

**Flash flood.** Flood of short duration with a relatively high peak discharge in which the time interval between the observable causative event and the flood is less than four to six hours.

**Flooded area.** Area covered by water when streamflow exceeds the carrying capacity of the channel or as a consequence of damming the channel downstream.

**Forecast (warning) lead time.** Interval of time between the issuing of a forecast (warning) and the expected occurrence of the forecast element.

**Forecast updating.** Adjustment of forecasts of events as new information becomes available.

**Forecast verification.** Determination of the accuracy of the forecasts through the statistical analysis of forecast errors.

**Gauge datum.** The vertical distance of the zero of a gauge referred to a certain datum level.

**Groundwater level.** Elevation, at a certain location and time, of the phreatic or the piezometric surface of an aquifer.

**Groundwater station.** A station at which data on groundwater are obtained on one or more of the following elements: water level, water temperature and other physical and chemical properties of water and rate and volume of abstraction and/or recharge.

**Hydrograph.** Graph showing the variation with time of water stage, discharge or velocity, or some other hydrological characteristic.

**Hydrological advisory.** Information on an expected hydrological phenomenon which is considered to be potentially dangerous.

**Hydrological drought.** A period of abnormally dry weather sufficiently prolonged to give rise to a shortage of water as evidenced by below normal streamflow and lake levels and/or the depletion of soil moisture and a lowering of groundwater levels.

**Hydrological forecast.** A statement of expected hydrological conditions for a specified period and for a specified locality.

**Hydrological observation.** The direct measurement or evaluation of one or more hydrological elements, such as stage, discharge, water temperature, etc.

**Hydrological observing station.** A place where hydrological observations or climatological observations for hydrological purposes are made.

**Hydrological station for specific purposes.** A hydrological station established for the observation of a specific element or elements, for the investigation of hydrological phenomena.

**Hydrological warning.** Emergency information on an expected hydrological phenomenon which is considered to be dangerous.

**Hydrometric station.** A station at which data on water in rivers, lakes or reservoirs are obtained on one or more of the following elements: stage, streamflow, sediment transport and deposition, water temperature and other physical properties of water, characteristics of ice cover and chemical properties of water.

**Ice forecast.** A statement of expected ice phenomena for a specified period and for a specified locality.

**Large river.** A river with a mean annual discharge at the mouth exceeding 2 000 m<sup>3</sup>/s or with a drainage basin exceeding 500 000 km<sup>2</sup>.

**Lateral inflow.** Inflow of water to a river, lake or reservoir along any reach from the part of the catchment adjacent to the reach.

**Long-term hydrological forecast.** Forecast of the future value of an element of the regime of a water body for a period extending beyond 10 days from the issue of the forecast.

**Major river.** A river with a mean annual discharge at the mouth exceeding 100 m<sup>3</sup>/s or with a drainage basin exceeding 100 000 km<sup>2</sup>.

**Medium-term hydrological forecast.** Forecast of the future value of an element of the regime of a water body for a period ending between 2 and 10 days from the issue of the forecast.

**\*Meteorological forecast (Forecast).** A statement of expected meteorological conditions for a specified time or period, and for a specified area or portion of air space.

**\*Meteorological observation (Observation).** The evaluation or measurement of one or more meteorological elements.

**\*Ordinary climatological station.** A climatological station at which observations are made at least once daily, including daily readings of extreme temperature and of amount of precipitation.

**\*Precipitation station.** A station at which observations of precipitation only are made.

**Precision of observation or of reading.** The smallest unit of division on a scale of measurement to which a reading is possible either directly or by estimation.

**\*Principal climatological station.** A climatological station at which hourly readings are taken, or at which observations are made at least three times daily in addition to hourly tabulation from autographic records.

**Principal hydrometric station.** A hydrometric station at which one or a number of elements, taking into account the significance of such elements in relation to the physical environment, are observed for a period of many years. The station is usually equipped with recording instruments.

**Rating curve.** A curve showing the relation between stage and discharge of a stream at a hydrometric station.

**\*Reference climatological station.** A climatological station the data of which are intended for the purpose of determining climatic trends. This requires long periods (not less than 30 years) of homogeneous records, where man-made environmental changes have been and/or are expected to remain at a minimum. Ideally the records should be of sufficient length to enable the identification of secular changes of climate.

**Seasonal hydrological forecast.** Forecast of the future value of an element of the regime of a water body for a season (usually covering a period of several months or more).

**Secondary hydrometric station.** A hydrometric station which is established only for a limited number of years to supplement the basic network of principal hydrometric stations.

**Short-term hydrological forecast.** Forecast of the future value of an element of the regime of a water body for a period ending up to two days from the issue of the forecast.

**Snow course.** A line laid out and permanently marked, along which the snow is sampled, or its depth measured, at appropriate times at stations separated by definite distances.

**Snow cover.** Snow accumulated on the ground.

**Snow depth.** The vertical distance between the surface of a snow layer and the ground, the layer being assumed to be evenly spread over the ground which it covers.

**Stage.** The vertical distance of the water surface of a stream, lake, or reservoir relative to a gauge datum.

**Storm surge.** The difference between the actual water level under the influence of a meteorological disturbance and the level which would have occurred in the absence of the meteorological disturbance.

**Streamflow.** The volume of water flowing through an open channel.

**Uncertainty.** The interval within which the true value of a quantity can be expected to lie with a stated probability.

**Water balance.** An inventory of water based on the principle that during a certain time interval, the total water gain to a given catchment area or body of water must equal the total water loss plus the net change in storage in the catchment.

**Water equivalent of snow cover.** Vertical depth of a water layer which would be obtained by melting a snow cover.

**Water supply forecast.** A statement of the expected volume of available water with associated time distribution and probabilities, whenever feasible for a specified period and for a specified area.

**Wind daily run.** The distance represented by integration of the wind speed over 24 hours measured at the point of observation.

## **SECTION D**

### **HYDROLOGY**

#### D.1 — HYDROLOGICAL INFORMATION AND WARNINGS

Chapter D.1.1 — Hydrological observing networks and stations

Chapter D.1.2 — Hydrological observations

Chapter D.1.3 — Hydrological forecasts and warnings

Chapter D.1.4 — Hydrological data transmission

Chapter D.1.5 — Water quality monitoring

#### D.2 — METEOROLOGICAL SERVICES FOR HYDROLOGY

#### D.3 — HYDROLOGICAL BIBLIOGRAPHY AND PUBLICATIONS



## D.1 — HYDROLOGICAL INFORMATION AND WARNINGS

### CHAPTER D.1.1 HYDROLOGICAL OBSERVING NETWORKS AND STATIONS

[D.1.1.] 1

#### **Classification of hydrological observing stations**

[D.1.1.] 1.1

Hydrological observing stations should be classified as:

- (a) Hydrometric stations;
- (b) Groundwater stations;
- (c) Climatological stations and precipitation stations for hydrological purposes;
- (d) Hydrological stations for specific purposes.

NOTE: Any station may fall under more than one of the above categories.

[D.1.1.] 1.2

Climatological stations for hydrological purposes should be classified as:

- (a) Reference climatological station;
- (b) Principal climatological station;
- (c) Ordinary climatological station;
- (d) Climatological station for specific purposes.

NOTES:

- (a) The definitions of stations listed above will be found under "Climatological station" in the Appendix of Volume I of the *Manual on the Global Observing System* (WMO-No. 544).
- (b) Any station may fall under more than one of the above categories.

[D.1.1.] 1.3

Hydrological stations for specific purposes should include those stations the data of which are necessary or used for purposes such as:

- (a) Determination of the water balance of catchments, lakes, reservoirs or glaciers;
- (b) Measurement of waves and currents on lakes and reservoirs;

- (c) Measurement of evaporation and evapotranspiration;
- (d) Measurement of soil moisture;
- (e) Determination of the physical and chemical properties of water.

NOTE: A hydrological station for specific purposes may serve more than one of the above purposes.

[D.1.1.] 2

#### **Networks of hydrological observing stations**

NOTE: Detailed guidance on design of networks including density is given in the *Guide to Hydrological Practices* (WMO-No. 168).

[D.1.1.] 2.1

Each Member should establish in its territory a network of hydrological observing stations.

NOTE: The design of hydrometric networks may be based on the concept of principal and secondary stations.

[D.1.1.] 2.2

The density of the network of hydrological observing stations should be adequate to permit the assessment, to an accuracy consistent with its purpose, of the elements of the hydrological cycle and other hydrological characteristics of any region.

[D.1.1.] 2.3

In planning networks of hydrological observing stations, account should be taken of the requirements of global or regional studies or programmes. In this regard all rivers with mean annual discharges at the mouth greater than 100 m<sup>3</sup>/s or catchment areas greater than 100 000 km<sup>2</sup> should be gauged.

[D.1.1.] 2.4

In planning networks of hydrological observing stations for international drainage basins, account should be taken of the requirements of the various Members concerned.

## [D.1.1.] 2.5

Observations of snow depth and water equivalent of snow cover should be made at a selection of climatological stations for hydrological purposes.

## [D.1.1.] 3

### Location of hydrological observing stations

## [D.1.1.] 3.1

Each station should be located at a site which permits correct exposure and functioning of the instruments and satisfactory instrumental and non-instrumental observations.

## [D.1.1.] 3.2

Each hydrometric and groundwater station should be located at a place and under an arrangement which will provide for the continued operation of the station for at least 10 years, unless it serves a specific purpose which justifies its functioning for a shorter period.

## [D.1.1.] 3.3

Climatological stations for hydrological purposes should be located as recommended in 2.8.5, 2.8.6 and 2.8.7 of Part III of Volume I of the *Manual on the Global Observing System* (WMO-No. 544).

NOTE: For convenience, 2.8.5, 2.8.6 and 2.8.7 of Part III of Volume I of the *Manual on the Global Observing System* are given below.\*

## [D.1.1.] 3.4

Each hydrological station for a specific purpose should be located at a place and under an arrangement which would provide for its proper operation for the required period of time.

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#### \* 2.8 Climatological stations

2.8.5 Each climatological station should be located at a place and under an arrangement that will provide for the continued operation of the station for at least ten years, and for the exposure to remain unchanged over a long period, unless it serves a special purpose that justifies its functioning for a shorter period.

2.8.6 Each reference climatological station should be sited with an adequate and unchanged exposure where the observations can be made in representative conditions. The surroundings of the station should not alter in time to such an extent as to affect the homogeneity of the series of observations.

2.8.7 The data relating to the elevation of a climatological station should be specified at least to the nearest five metres, except that for a station with a barometer the elevation should be specified to the nearest metre.

## [D.1.1.] 4

### Identification of hydrological observing stations

A hydrological observing station should be identified by its name and geographical coordinates and, where applicable, by the name of the river and major river basin, lake, reservoir or aquifer on or in which it is situated.

NOTE: The system of station index numbers for hydrological observing stations as used in the WMO international hydrological codes is given in Annex II to the Technical Regulations (*Manual on Codes* (WMO-No. 306), Volume I.1).

## [D.1.1.] 5

### Information relating to hydrological observing stations

## [D.1.1.] 5.1

Each Member should maintain an up-to-date directory of its hydrometric and groundwater stations and hydrological stations for specific purposes. The directory should contain the following information for each station, where applicable:

- (a) Name of river basin, name of river, lake reservoir or aquifer, name of station and its geographical coordinates;
- (b) Elevation of reference datum of water-level observations and/or elevation of the station and the geodetic system of reference;
- (c) Elevation of the surface of the ground at the well used for groundwater measurement;
- (d) Type of station (stream gauging, lake gauging, groundwater observations, soil moisture, precipitation, snow, evaporation, sediment and chemical quality);
- (e) Elements observed;
- (f) Instruments, observing programme, and time of observation;
- (g) Area of the catchment above the station in km<sup>2</sup>;
- (h) Information on artificial control and regulation of streamflow or water level and on conditions relating to ice;
- (i) A station history containing dates of beginning, closing or interruption of records, changes in the name of the station, changes in instrumentation or observing programme, changes in the units of recording and information on water abstractions, recharges and returns excluded or included in the observations as the case may be;
- (j) The name of the operating and supervising organization or institution;
- (k) Information on characteristics of the catchment or groundwater basin, including elevation, topography, geology, hydrogeology, vegetation, urban development and principal water resources and drainage development, as applicable.

## [D.1.1.] 5.2

The information relating to climatological stations for hydrological purposes should be maintained in the manner

described in 2.8.4 of Part III of Volume I of the *Manual on the Global Observing System* (WMO-No. 544).

NOTE: For convenience, 2.8.4 of Part III of Volume I of the *Manual on the Global Observing System* is given below.\*

[D.1.1.] 6

### Supervision of hydrological observing stations

[D.1.1.] 6.1

Each Member should arrange for its hydrometric and groundwater stations to be inspected at least once every six months to ensure the correct functioning of instruments and the maintenance of a high standard of observations. At least once annually, the gauge datum of a hydrometric station and of a groundwater station should be checked.

NOTE: These inspections are independent of routine inspection and maintenance of instruments and stations essential to efficient day-to-day working.

[D.1.1.] 6.2

The inspection of climatological stations for hydrological purposes should be arranged in the manner described in 3.1.9 of Part III of Volume I of the *Manual on the Global Observing System* (WMO-No. 544).

NOTE: For convenience, 3.1.9 of Part III of Volume I of the *Manual on the Global Observing System* is given below.\*\*

[D.1.1.] 6.3

The inspection of hydrological stations for special purposes should be arranged to meet the requirements of specific investigations.

#### \* 2.8 Climatological stations

2.8.4 Each Member should maintain an up-to-date directory of the climatological stations in its territory, giving the following information, often referred to as metadata, for each station:

- (a) Name and geographical coordinates;
- (b) Elevation of station;
- (c) A brief description of the local topography;
- (d) Category of station and details of observing programmes;
- (e) Exposure of instruments, including height above ground of thermometers, raingauges and anemometers;
- (f) A station history (dates of beginning of records, changes of site, closure or interruption of records, changes in the name of the station and important changes in the observing programme);
- (g) The name of the supervising organization or institution;
- (h) The datum level to which atmospheric pressure data of the station refer.

\*\* 3.1.9 Principal climatological stations should be inspected at least once every year; ordinary climatological and precipitation stations should be inspected at least once every three years. If possible, relevant inspections should occasionally be carried out during the winter season.

[D.1.1.] 7

### Hydrological observing system

[D.1.1.] 7.1

A hydrological observing system should include networks of hydrological observing stations, observers, observing devices, observation methods, procedures and communications links. It should provide hydrological observations according to a given plan.

[D.1.1.] 7.2

The plan of hydrological observations should generally include all major components of the hydrological water balance pertinent to both quantity and quality (including river bed surveys and sediment transport measurement).

[D.1.1.] 7.3

Each Member should establish and operate a hydrological observing system according to the national requirements.

[D.1.1.] 7.4

The hydrological observing system should be reviewed and revised as needed.

[D.1.1.] 8

### The functions and responsibilities of National Hydrological Services

[D.1.1.] 8.1

#### General

Each Member should ensure that there exists a national capacity to acquire, store and disseminate the water-related data and information required for sustainable development and management of its water resources, and for the mitigation of water-related hazards.

NOTE: Detailed guidance on the acquisition of water-related data and hydrological information is provided in the *Guide to Hydrological Practices* (WMO-No.168).

[D.1.1.] 8.2

#### Organization

Arrangements should be made appropriate to the Member's system of government, socio-economic and geographic characteristics, to ensure efficient and effective coordination and communication amongst the providers and users of water-related data and hydrological information. Where several agencies and/or levels of government have separate responsibility for providing or using information, their responsibilities and relationships should be clearly established and their efforts coordinated using appropriate administrative and legal arrangements.

NOTE: Examples of methods for organizing the acquisition of water-related data and hydrological information are provided in the *Casebook of Examples of Organization and Operation of Hydrological Services* (WMO-No. 461) and in *The Legal Basis and Role of Hydrological Services* (WMO/TD-No. 602).

## [D.1.1.] 8.3

**Functions**

In general, the routine functions of National Hydrological Services should include:

- (a) Coordinating the agencies which have responsibilities for acquiring and/or using water-related data and hydrological information;
- (b) Establishing the requirements of existing or possible future users of water-related data and hydrological information, including the requirements of other organizations that are collecting environmental and environmental-impact data in relation to land use and climate change;
- (c) Defining the standards (accuracy, precision, timeliness, accessibility, etc.) of the data which are implied by those requirements;
- (d) Designing, establishing and operating hydrometric networks to measure the various types of data required. Both “use-specific” and “basic” networks may be needed, which may be complementary or even overlapping, and which should be integrated;
- (e) Evaluating the adequacy of the existing network to ensure that the data and information collected meet the requirements of the users;
- (f) Establishing a quality assurance programme including staff qualifications, training and development, documentation of data collection and analysis methods and procedures, procurement and calibration of instrumentation, and review and approval of reports;
- (g) Developing methods for extrapolating data from sites at which measurements have been made to points or regions for which they are intended to be representative;
- (h) Collecting data, and maintaining quality control of the data collection process by inspection of both field installations and field practice;
- (i) Assembling water-related data and hydrological information generated by non-governmental, international and private sector organizations, and ensuring their future accessibility;
- (j) Transmitting, processing and archiving data, and maintaining control of the quality and security of the archived data;
- (k) Making the data accessible to users, when, where and in the form they require. For example this may include:
  - (i) The dissemination of hydrological forecasts and warnings;
  - (ii) The publication of yearbooks of basic data, in paper, microfiche or computer-compatible form;
  - (iii) The preparation of reports on water resources, in which data are comprehensively analysed. This may include media such as hydrological atlases or databases in geographical information systems;
  - (iv) Informative or educational material for use by the general public, the news media or schools;
  - (v) Design information;
  - (vi) Supporting global data centres, international programmes and projects;
- (l) Informing potential users of the information that is available to them, and assisting them to make the best use of it;
- (m) Adapting or developing new methods and technology, related to:
  - (i) Network design;
  - (ii) Instrumentation and methods of observation;
  - (iii) Data transmission and processing;
  - (iv) Hydrological forecasting;
  - (v) Data analysis, interpretation and presentation;
- (n) Carrying out research into hydrological and related processes, in order to assist the user in interpreting and understanding the data;
- (o) Securing qualified staff and providing staff training and development;
- (p) Collaborating with agencies which acquire water-related or other relevant information, such as water quantity and quality, sediment, hydrogeological, water use, topographic and land use, or meteorological information;
- (q) Participating with foreign water-sector agencies in international programmes and projects;
- (r) Furnishing hydrological information for inclusion in countries’ periodic reports on the state of the environment;
- (s) Undertaking water resources assessment studies for development purposes;
- (t) Participating in the planning, development and management of water resources projects.

## CHAPTER D.1.2 HYDROLOGICAL OBSERVATIONS

[D.1.2.] 1

### Composition of observations

[D.1.2.] 1.1

At a hydrometric station, observations should be made of some or all of the following elements:

- (a) River, lake or reservoir stage;
- (b) Streamflow;
- (c) Sediment transport and/or deposition;
- (d) Temperature and other physical properties of the water of a river, lake or reservoir;
- (e) Characteristics and extent of ice cover on rivers, lakes and reservoirs;
- (f) Chemical and biological properties of the water of a river, lake or reservoir.

[D.1.2.] 1.2

At a climatological station for hydrological purposes, observations should be made of one or more of the elements necessary for the quantitative estimation of the atmospheric phases of the hydrological cycle, as follows:

- (a) Precipitation:
  - (i) Amount;
  - (ii) Time of occurrence;
  - (iii) Form (e.g. rain, snow, sleet);
  - (iv) Character (continuous, intermittent, scattered showers, etc.);
  - (v) Intensity;
- (b) Air temperature (including extreme temperatures);
- (c) Air humidity;
- (d) Wind — speed and direction (10-minute wind average);  
— daily run;
- (e) Amount and type of cloud;
- (f) Snow cover:
  - (i) Snow depth;
  - (ii) Density;
  - (iii) Water equivalent;
- (g) Evaporation (measured with evaporation pan);

- (h) Solar radiation;
- (i) Sunshine;
- (j) Soil temperature;
- (k) Atmospheric pressure;
- (l) Soil moisture.

[D.1.2.] 1.3

At groundwater stations, observations should be made of one or more of the following elements:

- (a) Water level;
- (b) Temperature and other physical properties of the water;
- (c) Chemical properties;
- (d) Rate and volume of abstraction or recharge.

[D.1.2.] 1.4

At hydrological stations for specific purposes, observations should be made of those elements which are appropriate to the purpose of the station (see [D.1.1.] 1.3) and may include some of those elements which are listed in [D.1.2.] 1.1 and [D.1.2.] 1.2.

[D.1.2.] 2

### Observing and reporting programme for hydrological observing stations

NOTE: In addition to the regulations in this section, detailed guidance on observing programmes is given in the *Guide to Hydrological Practices* (WMO-No. 168).

[D.1.2.] 2.1

Where automatic registration is not available, observations of elements for hydrological purposes should be made at regular intervals which are appropriate for the elements and purposes.

[D.1.2.] 2.2

Uniformity in time of observations should generally be observed within a catchment area.

## [D.1.2.] 2.3

For rivers under flood conditions or where there are variable controls, special measurements should be made at intervals frequent enough to define the hydrograph.

## [D.1.2.] 2.4

The reporting interval of river, lake and reservoir stages should be prescribed to meet the intended operational use.

## [D.1.2.] 2.5

When sudden and dangerous increases in river levels occur, observations should be made and reported as soon as possible without regard to the usual time of observation, to meet the intended operational use.

## [D.1.2.] 2.6

The observing and reporting programme of climatological stations for hydrological purposes should be carried out as described in 2.8.12, 2.8.13 and 2.8.14 of Part III of Volume I of the *Manual on the Global Observing System* (WMO-No. 544).

NOTE: For convenience 2.8.12, 2.8.13 and 2.8.14 of Part III of Volume I of the *Manual on the Global Observing System* are given below.\*

## [D.1.2.] 2.7

Hydrological information for international purposes should be open text or in the appropriate code forms on the bases of bilateral or multilateral agreement.

NOTE: The regulation governing exchanges in international code (*Technical Regulations*, Volume I (1988 edition), [A.2.3.] 1.1.1) is given below.\*\*

## \* 2.8. Climatological observations

2.8.12 Each Member should arrange that observations at any climatological station be made at fixed hours, according to either Universal Time Coordinated (UTC) or Local Mean Time, which remain unchanged throughout the year.

2.8.13 When two or more observations are made at a climatological station, they should be arranged at times that reflect the significant diurnal variations of the climatic elements.

2.8.14 When changes are made in a network of the times of climatological observations, simultaneous observations should be carried out at a skeleton network of representative stations for a period covering the major climatic seasons of the area at the old times of observation and at the new ones.

## \*\* [A.2.3.] 1.1.1

Coded information exchanged for international purposes shall be in the appropriate international code forms, specified in Annex II (*Manual on Codes* (Publication No. 306), Volume I).

NOTE: Coded information exclusively for exchange between one Member and another may be in other forms by bilateral agreement.

## [D.1.2.] 3

**Equipment and methods of observation**

NOTE: In addition to the regulations in this section, detailed guidance about equipment and methods of observation is given in the *Guide to Hydrological Practices* (WMO-No. 168).

## [D.1.2.] 3.1

Each Member should equip its stations with properly calibrated instruments and should arrange for these stations to follow adequate observational and measuring techniques to ensure that the measurements and observations of the various hydrological elements are accurate enough to meet the needs of hydrology.

## [D.1.2.] 3.1.1

Specifications of facilities, equipment and procedure to be used for the calibration of current meters should be as specified in the annex, section I — Calibration of current meters in straight open tanks.

## [D.1.2.] 3.1.2

Devices for measurement of water levels should conform to the specifications given in the annex, section II — Water-level measuring devices.

## [D.1.2.] 3.1.3

Equipment for measurement of depth of water and for suspending current meters and sediment samplers should conform to the specifications given in the annex, section III — Direct depth sounding and suspension equipment and section XI — Echo sounders for water depth measurements.

## [D.1.2.] 3.1.4

Operational requirements, construction, calibration and maintenance of rotating element current meters should be as specified in the annex, section IV — Rotating element type current meters.

## [D.1.2.] 3.1.5

Functional requirements for the measurement of discharge using weirs should be as specified in the annex, section V — Precalibrated weirs for the determination of discharge.

## [D.1.2.] 3.1.6

Functional requirements for the measurement of discharge using flumes should be as specified in the annex, section IX — Flow measurement using flumes.

## [D.1.2.] 3.1.7

Conditions and requirements for the use of dilution methods for measurement of discharge in open channels should be as specified in the annex, section X — Dilution methods for measurement of flow.

## [D.1.2.] 3.1.8

Equipment and functional requirements for the use of the moving-boat method for discharge measurement should be as specified in the annex, section XII — Discharge measurements by the moving-boat method.

## [D.1.2.] 3.2

Each Member should have access to a sediment laboratory which is equipped for two principal functions:

- (a) The determination of suspended-sediment concentrations of samples collected from streams;
- (b) The determination of the particle size distribution of suspended sediment, stream-bed material and reservoir deposits.

## [D.1.2.] 3.3

The method for measuring discharge at a new site should be selected on the basis of the streamflow characteristics at the site determined from water-velocity observations at various verticals in a cross-section and depths at each vertical.

## [D.1.2.] 3.3.1

The establishment and operation of a hydrometric station for measuring discharge should conform to the specifications given in the annex, section VI — Establishment and operation of a hydrometric station.

## [D.1.2.] 3.4

The number of discharge measurements at a stream gauging station should be adequate to define the rating curve for the station at all times.

## [D.1.2.] 3.4.1

Methods of determining the stage-discharge relation (rating curve) for a station should be as specified in the annex, section VII — Determination of the stage-discharge relation.

## [D.1.2.] 3.5

Uncertainty in the observation of water levels of rivers, estuaries, lakes, reservoirs and groundwater should not exceed:

- (a) In general, 10 mm at the 95 per cent confidence level;
- (b) Under difficult conditions, 20 mm at the 95 per cent confidence level.

## [D.1.2.] 3.6

River discharges should be measured to an accuracy commensurate with flow and local conditions. Percentage uncertainty of the discharge measurement should not exceed:

- (a) In general, 5 per cent at the 95 per cent confidence level;
- (b) Under difficult conditions, 10 per cent at the 95 per cent confidence level.

## [D.1.2.] 3.7

The method of evaluating the uncertainty in discharge measurements should conform to the specifications given in the annex, section VIII — Estimation of uncertainty of discharge measurements.

## [D.1.2.] 3.8

Uncertainty in temperature observations in rivers, lakes, reservoirs and groundwater should not exceed:

- (a) In general, 0.1°C at the 95 per cent confidence level;

- (b) Under difficult conditions, 0.5°C at the 95 per cent confidence level.

## [D.1.2.] 3.9

Observations made at climatological stations for hydrological purposes should meet the accuracy requirements which are generally associated with those types of observations.

NOTE: Detailed guidance about instruments and methods of observation for climatological stations is given in the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No. 8).

## [D.1.2.] 3.10

Measurements of the depth and water equivalent of the snow cover should be made in permanently marked areas or snow courses where snow surveys are taken every year. Those areas or snow courses should be located to provide a reliable index of the water equivalent of the snow cover over a great part of a river basin.

## [D.1.2.] 3.11

Suspended-sediment samples should be taken in such a manner as to yield concentrations truly representative of the mean suspended-sediment concentration for the entire cross-section of the stream.

## [D.1.2.] 4

### Collection, processing and publication of hydrological data

NOTE: Detailed guidance regarding the collection, processing and publication of hydrological data is given in the *Guide to Hydrological Practices* (WMO-No. 168).

## [D.1.2.] 4.1

Each Member should collect and preserve its hydrological records.

## [D.1.2.] 4.2

Each Member should make the necessary arrangements to facilitate the retrieval and analysis of its hydrological data by automatic data-processing equipment.

## [D.1.2.] 4.3

Each Member should maintain in its archives an up-to-date inventory of the hydrological data available in its territory.

## [D.1.2.] 4.4

The time units used in processing hydrological data for international exchange should be selected from the following:

- (a) The Gregorian calendar year;
- (b) The months of this calendar;
- (c) The mean solar day, from midnight to midnight, according to the zonal time, when the data permit;
- (d) Other periods by mutual agreement in the case of international drainage basins or in the case of drainage basins in the same type of region.

## [D.1.2.] 4.5

Sums or averages of all or most of the following data from a selection of hydrometric and groundwater stations should be computed for each month and for the year:

- (a) River, lake, reservoir stages or groundwater levels;
- (b) Streamflow;
- (c) Sediment transport;
- (d) Water temperature;
- (e) Chemical properties of water.

## [D.1.2.] 4.6

For selected hydrometric stations the following characteristics for each year should be processed:

- (a) Maximum instantaneous and minimum daily mean values of water stages and streamflow;
- (b) Statistical frequency of mean daily water stages and/or mean daily discharges;
- (c) Mean weekly suspended-sediment discharges;
- (d) Measured values of the concentration of chemical constituents in streams.

## [D.1.2.] 4.7

For selected groundwater stations the following characteristics for each year should be processed:

- (a) Maximum and minimum values of water levels;
- (b) Statistical frequency of mean daily water levels;
- (c) Measured values of the concentration of chemical constituents in the water.

## [D.1.2.] 4.8

Members should compute long-term annual and monthly averages of some elements for selected hydrological observing stations within their territory where there are at least 10 years of continuous records.

## [D.1.2.] 4.9

Each Member should ensure the annual publication of hydrological data in an appropriate form.

NOTE: Monthly reports plus an annual summary may constitute an annual report.

## [D.1.2.] 4.9.1

In the case where a station falls under two or more categories (refer to note under [D.1.1.] 1.1), selected data from such stations should be published under each appropriate category.

## [D.1.2.] 4.9.2

The information contained in the annual publications should consist of:

- (a) A list for each hydrometric and groundwater station giving, where applicable:

- (i) Name of river, lake, reservoir or aquifer, name of station and geographical coordinates;
- (ii) Elevation of reference datum for observations in metres;
- (iii) Area of the catchment above the station in km<sup>2</sup>;
- (iv) Category of station and details of observing programme, including observation times;
- (v) Instrumentation;
- (vi) Period of record;
- (vii) Information on principal upstream diversions and artificial controls;

- (b) A number of tables containing hydrological data and their statistical characteristics, where applicable.

## [D.1.2.] 4.9.3

Whenever long-term averages are published, the period to which they refer should be indicated.

## [D.1.2.] 4.9.4

If the main language of a publication is not English, French, Russian or Spanish, all headings of tables should be in one of these official languages or in internationally recognized symbols or letters (key illustrative tables may be sufficient).

NOTE: Although Arabic and Chinese are official languages of WMO, Congress has not yet approved their use in all aspects of the work of WMO.

## [D.1.2.] 4.10

Except where WMO practices indicate otherwise, Members should use the International System of Units (SI units), as defined by the International Organization for Standardization (ISO), in scientific publications and other scientific documents.

NOTE: Guidance on the use of these units is given in the *International Meteorological Tables* (WMO-No. 188) and in *ISO Standards Handbook 2, Units of Measurement, 1979*.

## [D.1.2.] 4.10.1

Recommended symbols and units used for hydrological purposes should be as given in the appendix.

## [D.1.2.] 5

**Safety procedures**

## [D.1.2.] 5.1

**Each Member shall ensure that proper safety procedures are specified, documented and utilized in all its operations.**

## [D.1.2.] 5.2

**A handbook for national safety procedures shall be established which stresses precautions and practices specific to the conditions in the country concerned. These procedures must also satisfy all of the requirements of the country including legal, health and safety codes.**

NOTE: In addition to the regulations in this section, countries are referred to the *Guide to Hydrological Practices* (WMO-No. 168), fifth edition, which contains detailed guidance on safety procedures.

**APPENDIX**  
(See [D.1.2.] 4.10.1)

**SYMBOLS AND UNITS**

NOTE: Where international symbols exist these have been used where appropriate and are indicated as ISO in the last column (see Table 1.4 for modifiers of symbols).

Table 1.1  
**Recommended symbols and units**

<i>Item</i>	<i>Element</i>	<i>Symbol</i>	<i>Units</i>	<i>Remarks</i>
1	Acceleration due to gravity	<i>g</i>	m/s <sup>2</sup>	ISO
2	Albedo	<i>r</i>	Expressed as a decimal	
3	Area (cross-sectional) (drainage basin)	<i>A</i>	m <sup>2</sup> km <sup>2</sup>	ISO ISO ha also in use
4	Chemical quality		mg/l	(for dilute solutions) ppm also in use
5	Chézy coefficient $\left[ \nu / (R_h S)^{1/2} \right]$	<i>C</i>	m <sup>1/2</sup> /s	ISO
6	Conveyance	<i>K</i>	m <sup>3</sup> /s	ISO
7	Degree day	<i>D</i>	Degree day	
8	Density	<i>p</i>	kg m <sup>-3</sup>	ISO
9	Depth, diameter, thickness	<i>d</i>	m cm	ISO
10	Discharge (river flow) (wells) (unit area <i>Q/A</i> , or partial)	<i>Q</i> <i>Q<sub>we</sub></i> <i>q</i>	m <sup>3</sup> /s l/s m <sup>3</sup> /s km <sup>2</sup> l/s km <sup>2</sup>	ISO ISO
11	Drawdown	<i>s</i>	m cm	
12	Dynamic viscosity (absolute)	<i>η</i>	Pa s	
13	Evaporation	<i>E</i>	mm	
14	Evapotranspiration	<i>E<sub>T</sub></i>	mm	
15	Froude number	<i>Fr</i>	Dimensionless number	ISO
16	Head, elevation	<i>z</i>	m	ISO

Item	Element	Symbol	Units	Remarks
17	Head, pressure	$h_p$	m	
18	Head, static (water level) = $z + h_p$	$h$	cm m	ISO
19	Head, total = $z + h_p + h_v$	$H$	m	ISO
20	Head, velocity = $v^2/2g$	$h_v$	cm m	
21	Hydraulic conductivity (permeability)	$K$	cm/s	m/d also in use
22	Hydraulic diffusivity	$D$	cm <sup>2</sup> /s	
23	Hydraulic radius = $A/P_w$	$R_h$	m	ISO
24	Ice thickness	$d_g$	cm	
25	Infiltration	$f$	mm	
26	Infiltration rate	$I_f$	mm/h	
27	Intrinsic permeability	$k$	10 <sup>-8</sup> cm <sup>2</sup>	
28	Kinematic viscosity	$\nu$	m <sup>2</sup> /s	ISO
29	Length	$l$	cm m km	ISO
30	Manning's coefficient = $R_h^{2/3} S^{1/2} / \nu$	$n$	s/m <sup>1/3</sup>	ISO
31	Mass	$m$	kg g	ISO
32	Porosity	$n$	%	$\alpha$ may also be used if needed
33	Precipitation	$P$	mm	
34	Precipitation intensity	$I_P$	mm/h	
35	Pressure	$p$	Pa	mb or mbar also in use, see also: Head, pressure
36	Radiation* (quantity of radiant energy per unit area)	$R$	J/m <sup>2</sup>	
37	Radiation intensity* (flux per unit area)	$I_R$	J/m <sup>2</sup> s	
38	Radius of influence	$r_I$	m	
39	Recession coefficient	$C_r$	Expressed as a decimal	
40	Relative humidity (moisture)	$U$	%	
41	Reynolds number	$Re$	Dimensionless number	ISO
42	Runoff	$R$	mm	

\* General terms: for detailed terminology and symbols see the *Guide to Meteorological Instruments and Methods of Observation* (WMO-No.8).

<i>Item</i>	<i>Element</i>	<i>Symbol</i>	<i>Units</i>	<i>Remarks</i>
43	Sediment concentration	$c_s$	kg/m <sup>3</sup>	ppm also in use
44	Sediment discharge	$Q_s$	t/d	
45	Shear stress	$\tau$	Pa	ISO
46	Slope (hydraulic, basin)	$S$	Dimensionless number	ISO
47	Snow cover	$A_n$	%	
48	Snow depth	$d_n$	cm	
49	Snowmelt	$M$	mm	normally expressed as daily
50	Soil moisture	$U_s$	% volume	% mass also in use
51	Soil moisture deficiency	$U_s'$	mm	
52	Specific capacity = $Q_w/d$	$C_s$	m <sup>2</sup> /s	
53	Specific conductance	$\kappa$	$\mu\text{S}/\text{cm}$	at $\theta = 25^\circ\text{C}$
54	Specific yield	$Y_s$	Expressed as a decimal	
55	Storage	$S$	m <sup>3</sup>	
56	Storage coefficient (groundwater)	$C_s$	Expressed as a decimal	
57	Sunshine	$n/N$	Expressed as a decimal	actual ( $n$ )/ possible ( $N$ ) hours
58	Surface tension	$\sigma$	N/m	ISO
59	Temperature	$\theta$	°C	ISO $t$ also in use
60	Total dissolved solids	$m_d$	mg/l	(for dilute solutions) ppm also in use
61	Transmissivity	$T$	m <sup>2</sup> /d	
62	Vapour pressure	$e$	Pa	mb or mbar also in use
63	Velocity (water)	$v$	m/s	ISO
64	Volume	$V$	m <sup>3</sup>	ISO
65	Water equivalent of snow	$w_n$	mm	
66	Weber number	$We$	Dimensionless number	
67	Wetted perimeter	$P_w$	m	
68	Width (cross-section, basin)	$b$	m km	ISO
69	Wind speed	$u$	m/s	km/h, kn (or kt) also in use

Table 1.2  
**Miscellaneous symbols**

<i>Item</i>	<i>Element</i>	<i>Symbol</i>	<i>Remarks</i>
1	concentration	<i>c</i>	ISO
2	coefficient (in general)	<i>C</i>	ISO
3	difference	$\Delta$	ISO, values expressed in same units
4	inflow	<i>I</i>	
5	lag time	$\Delta t$	various units
6	load	<i>L</i>	
7	number of (or rank)	<i>m</i>	ISO
8	outflow	<i>O</i>	
9	recharge	<i>f</i>	(see Infiltration in Table 1.1)
10	total number	<i>N</i>	

Table 1.3  
**Units used in Table 1.1**

<i>Item</i>	<i>Unit</i>	<i>Symbol</i>	<i>Remarks</i>
1	centimetre	cm	ISO
2	day	d	ISO
3	degree Celsius	°C	ISO
4	gram	g	ISO
5	hectare	ha	
6	hour	h	ISO
7	joule	J	ISO
8	kilogramme	kg	ISO
9	kilometre	km	ISO
10	knot	kn, kt	
11	litre	l	ISO
12	metre	m	ISO
13	microsiemens	$\mu\text{S}$	
14	millibar	mb, mbar	ISO
15	milligram	mg	ISO
16	millimetre	mm	ISO
17	minute	min	ISO
18	newton	N	ISO
19	parts per million	ppm	
20	pascal	Pa	ISO
21	percentage	%	
22	second	s	ISO
23	tonne (metric ton)	t	ISO
24	year	a	ISO

Table 1.4  
**Modifiers to be used as subscripts to symbols in Table 1.1**

<i>Item</i>	<i>Modifier (subscript)</i>	<i>Symbol</i>	<i>Remarks</i>
1	actual (or measured)	–	bar under the symbol
2	air	a	
3	base	b	
4	channel	ch	
5	computed	c	
6	critical	cr	
7	hydraulic	h	
8	ice	g	
9	initial	o	reads “zero”
10	intensity (rate)	i	
11	limiting (or of influence)	l	
12	maximum value	max	
13	mean value	–	ISO – bar over the symbol
14	minimum value	min	
15	observed	ob	
16	overland	ov	
17	pressure	<i>p</i>	
18	recession	r	
19	sediment, soil, surface, specific	s	
20	snow	n	
21	subsurface	ss	
22	time-dependent (or at given time)	t	
23	tracer	tr	
24	vapour	e	
25	velocity	<i>v</i>	
26	water, wetted	w	
27	well (tube well)	we	



## CHAPTER D.1.3 HYDROLOGICAL FORECASTS AND WARNINGS

[D.1.3.] 1

### **General**

Each Member should ensure that hydrological forecasts and warnings are issued for protection from hazardous hydrological conditions and for purposes of water management operations.

NOTE: Detailed guidance regarding the principles and practice of hydrological forecasting is given in the *Guide to Hydrological Practices* (WMO-No. 168), fifth edition, Part E.

[D.1.3.] 2

### **Organization of the service**

The hydrological forecasting service should be organized in such a way that efficient coordination and communication, including data collection and exchange of hydrological data, is ensured between all its departments and centres and between the forecasting service and those responsible for the provision of meteorological data and forecasts. Where they are separate organizations, the division of responsibility and authority between the Hydrological Service and the Meteorological Service should be clearly defined.

NOTE: Detailed information on hydrological forecasting services is given in the *Guide to Hydrological Practices* (WMO-No. 168), fifth edition, 41.4.

[D.1.3.] 3

### **Forecasting and warning programme**

[D.1.3.] 3.1

#### **Types of forecasts, warnings and advisories to be issued**

[D.1.3.] 3.1.1

Hydrological forecasts should be classified according to forecast periods as (see definitions):

- (a) Short-term hydrological forecasts (up to 2 days);
- (b) Medium-term hydrological forecast (2 to 10 days);
- (c) Long-term hydrological forecast (more than 10 days);
- (d) Seasonal hydrological forecast (several months).

[D.1.3.] 3.1.2

The basic hydrological elements for which forecasts should be issued are as follows:

- (a) Water levels (river/lake stage) for specified times; also velocity and discharge where needed for navigation, water supply and/or other requirements;
- (b) In flood periods, the times when water level rises above the alarm level, the peak stage (velocity and/or discharge) and its time of occurrence;
- (c) Ice conditions on rivers, lakes and reservoirs;
- (d) Volume and time distribution of runoff for various periods of time (periods of high and low flows, month, season, year) and whenever feasible, associated probabilities;
- (e) Abnormally low stages or discharges (drought conditions);
- (f) Storm surges and wave heights in estuaries, coastal zones, large lakes and reservoirs;
- (g) Selected water quality parameters.

NOTE: See the *Guide to Hydrological Practices* (WMO-No. 168), fifth edition, 41.2.

[D.1.3.] 3.1.3

Hydrological information should be issued on a routine basis as follows:

- (a) Information regarding the actual hydrological situation (including, as appropriate, stages discharges and water quality parameters for rivers, estuaries, coastal zones, lakes and reservoirs; ice conditions; groundwater levels; soil moisture; precipitation; water equivalent of snow cover);
- (b) Assessment of conditions which are conducive to high levels and runoff;
- (c) Assessment of conditions which may be indicative of future drought conditions.

[D.1.3.] 3.2

#### **Data requirements**

Networks should be designed taking into account the special needs of hydrological forecasts. Each member should arrange for the timely collection and distribution of

the data required for the preparation of the forecasts and advisories indicated in [D.1.3.] 3.1.

#### [D.1.3.] 3.2.1

##### **Collection and transmission of data**

The precision and frequency of measurement of hydrological data should be as tabulated in the *Guide to Hydrological Practices* (WMO-No. 168), fifth edition, Part E.

NOTES:

- (a) See also D.1.1, D.1.2 and D.1.4.
- (b) Hydrological forecasting has special network and data collection requirements. Detailed guidance on data collection and transmission is given in the *Guide to Hydrological Practices* (WMO-No. 168), fifth edition, Part C, and in the *HOMS Reference Manual*, Sections E and F.

#### [D.1.3.] 3.2.2

##### **Meteorological data**

Desirable precision of observation and frequency of measurement of meteorological data for hydrological forecasting purposes should be as indicated in [D.2.] 2.3.

#### [D.1.3.] 3.2.2.1

##### **Precipitation data and quantitative precipitation forecasts (QPF)**

The hydrological forecaster should be supplied with QPFs on a regular basis and these should be frequently updated during flood situations. The meteorological forecaster making the QPF should have available all current precipitation observations including those made primarily for hydrological purposes.

#### [D.1.3.] 3.2.2.2

##### **Meteorological observational and forecast data other than precipitation**

The following types of meteorological information, data and forecasts should be made available at standard times to the hydrological forecaster:

- (a) Temperature, including:
  - (i) Current data;
  - (ii) Forecasts of abrupt and sizeable changes;
  - (iii) Forecasts of unusually high or low temperatures;
- (b) Wind, including:
  - (i) Current data;
  - (ii) Forecast of unusually high winds;
  - (iii) When hydrologically significant, forecast of abrupt changes in wind direction;
- (c) Meteorological data related to evapotranspiration computations:
  - (i) Solar radiation or per cent sunshine;
  - (ii) Dew point temperature or relative humidity;
  - (iii) Observed pan evaporation.

#### [D.1.3.] 3.3

##### **Selection of techniques**

In selecting a forecasting technique, the hydrological forecasting service should take into account the forecast needs,

the resources available and, among others, the experience obtained through investigations and intercomparison of techniques conducted during the last two decades.

NOTE: Information on the relative capabilities and resources requirements of hydrological models is given in the *Guide to Hydrological Practices* (WMO-No. 168), fifth edition, 33.2, Chapter 34, 39.1, 39.2, 39.3 and Chapter 43, in *Intercomparison of conceptual models used in operational hydrological forecasting* (WMO-No. 429), *Intercomparison of models of snowmelt runoff* (WMO-No. 646) and in the *HOMS Reference Manual*, Sections J and K.

#### [D.1.3.] 3.4

##### **Administrative considerations**

#### [D.1.3.] 3.4.1

##### **Use of QPF in hydrological forecasting**

#### [D.1.3.] 3.4.1.1

Hydrological forecasting should be based on whatever combination of observed and forecast rainfall provides the most timely and accurate forecast.

#### [D.1.3.] 3.4.1.2

The decision to use QPF in a hydrological forecast should be an operational decision based on the following hydrological information relative to the forecast event:

- (a) The probable error in the QPF as regards volume, location and timing;
- (b) How such errors propagate through the hydrological forecasting technique and affect the accuracy of the hydrological forecast;
- (c) How the user of the forecast is affected by varying forecast lead time and by varying levels of forecast accuracy.

#### [D.1.3.] 3.4.2

##### **Forecast adjustment**

Hydrological forecast updating should be performed in such a manner as to make full use of the forecaster's knowledge and judgement. Where available, automated adjustment techniques should be used to aid the forecast adjustment process.

NOTE: Information on forecast adjustment techniques is given in the *Guide to Hydrological Practices* (WMO-No. 168), fifth edition, 43.10 and in the *HOMS Reference Manual*, Section J.

#### [D.1.3.] 3.4.3

##### **Uncertainty in hydrological forecasts**

The hydrological forecasting service should establish administrative regulations concerning the manner in which hydrological forecasts, and their probable errors, are expressed. The service should also undertake whatever educational activities are needed to assure that the forecast user understands not only the forecast, but also its probable error.

[D.1.3.] 3.5

**Flash floods and storm surges**

In areas where flash floods or storm surges are a problem, the hydrological forecasting service should concentrate on providing whatever automation and administrative procedures are needed to accomplish:

- (a) Rapid transmission of field observations to the forecast office;
- (b) Rapid computation of the forecast;
- (c) Rapid transmission of the forecast to the ultimate user.

The service should provide generalized flash flood or storm surge warnings without delaying to prepare refined, site-specific forecasts.

[D.1.3.] 3.6

**Drainage flooding**

In areas where drainage flooding and lateral inflow occur, the rainfall intensity which is likely to cause problems should be ascertained. Warnings should be issued when such intensities are being experienced or are considered to be imminent. The hydrological forecasting service should assure that all concerned, including the users, understand the difference between drainage flooding and flooding caused by rivers and storm surges.

[D.1.3.] 3.7

**Dam breaks**

The hydrological forecasting service should conduct a survey of dams in its area. For those dams whose failure would cause extensive property damage and/or loss of life, advance computation should be made of the downstream flood profile and the alarm levels based on various types of assumed failures including the worst possible case. These should be available for immediate use in the event of a failure.

NOTE: Technical information regarding the routing of hydrographs resulting from dam failure are given in the *Guide to Hydrological Practices* (WMO-No. 168), fifth edition, 44.33 and in the *HOMS Reference Manual*, Sections J and K.

[D.1.3.] 3.8

**Estuaries and coastal zones**

Where the land area adjacent to an estuary or a coast is subject to damage by flooding or where extreme stages and/or discharges in an estuary affect navigation activities, forecasts of stages and/or discharges in the estuary should be issued.

NOTE: Information on the technical aspects of estuary forecasting is given in the *Guide to Hydrological Practices* (WMO-No. 168), fifth edition, 43.8 and 44.4. A service faced with an estuary problem and not having the resources to apply a dynamic routing procedure to it may obtain adequate results by using an empirical graphical relationship involving upstream discharge, open sea surge and estuary stage.

[D.1.3.] 3.9

**Low flow forecasts**

[D.1.3.] 3.9.1

**Water supply forecasts**

Where needed, long-term (usually monthly or seasonal) forecasts of the flow of rivers should be made to enable the efficient operation of water supply systems. Usually, such forecasts will need to take account of future weather and therefore, in general, they should be given in probabilistic terms.

NOTES:

- (a) Information on techniques used for making water supply forecasts is given in the *Guide to Hydrological Practices* (WMO-No. 168), fifth edition, 44.5.
- (b) Techniques for water supply forecasts, using stochastic inputs to continuous streamflow models or probabilistic analyses of model output based on historical data, are covered in the *Guide to Hydrological Practices* (WMO-No. 168), fifth edition, 43.11 and 44.5.

[D.1.3.] 3.9.2

**Drought forecasts**

The hydrological forecasting service should remain constantly alert for conditions which may indicate the onset of a period of hydrological drought and should release its assessment of the situation on a regular basis.

NOTE: See the *Guide to Hydrological Practices* (WMO-No. 168), fifth edition, 35.4 and 35.5.

[D.1.3.] 3.10

**Cold region phenomena**

[D.1.3.] 3.10.1

**Snow**

NOTE: See the *Guide to Hydrological Practices* (WMO-No. 168), fifth edition, Chapter 45 for snowmelt forecasts and 42.6.2 for remote sensing

- (a) In areas where precipitation may fall as either snow or rain, reporting procedures should assure that the character of precipitation as well as its amount are reported to the forecaster.
- (b) In accessible portions of river basins, snow surveys should be made as often as necessary to maintain a continuing quantitative assessment of the snow cover situation.

[D.1.3.] 3.10.2

**Ice forecasts**

NOTE: See the *Guide to Hydrological Practices* (WMO-No. 168), fifth edition, Chapter 46.

The hydrological forecasting service should determine which river reaches are prone to the formation of ice and ice jams. During cold weather, such areas should be reconnoitred

regularly. The expected effects of ice jams on water levels should also be assessed.

[D.1.3.] 3.11

### **Forecast dissemination**

The hydrological forecasting service should be concerned not only with preparing the forecasts and warnings, but also with their dissemination to the ultimate users and their presentation in a form understandable to them. Special emergency plans for informing the public and various responsible bodies should be developed.

NOTE: A discussion of dissemination methods and considerations is given in the *Guide to Hydrological Practices* (WMO-No. 168), fifth edition, 41.5.

[D.1.3.] 3.12

### **Forecast evaluation/verification**

The hydrological forecasting service should constantly monitor the quality of its output. Such monitoring should lay emphasis on the values of the forecasts to potential users and hence the evaluation should be based on their accuracy

and timeliness, as well as the responsiveness of the users when forecasts and warnings are issued.

NOTE: Information on operational forecast verification is given in the *Guide to Hydrological Practices* (WMO-No. 168), fifth edition, 41.3 and 41.3.1.

[D.1.3.] 3.13

### **User education**

The value of hydrological forecasts and warnings, in particular flood forecasts, depends upon the degree of understanding and the response of the recipients. To ensure the correct response to flood forecasts, particularly flash floods, a continuing public education programme should be established to cover the interpretation of flood forecasts and the appropriate action to be taken.

[D.1.3.] 3.14

### **International basins**

The exchange of hydrological forecasts and warnings on international basins should be organized on the basis of bilateral or multilateral agreement (see note to [D.1.2.] 2.7).

## **CHAPTER D.1.4**

### **HYDROLOGICAL DATA TRANSMISSION**

[D.1.4.] 1

#### **General**

[D.1.4.] 1.1

Each Member should ensure the transmission of hydrological observations necessary to meet national requirements.

[D.1.4.] 1.2

Transmission facilities should be organized for the international exchange of hydrological data, forecasts and warnings on the basis of bilateral or multilateral agreement (see note to [D.1.2.] 2.7).

[D.1.4.] 1.2.1

The Global Telecommunication System (GTS) of the World Weather Watch (WWW) should be used for international exchange of hydrological data, where practical and economical.

NOTE: Alternative systems may be more appropriate for the transmission of hydrological data not required in real time.

[D.1.4.] 2

#### **System and plan for data transmission**

[D.1.4.] 2.1

A data transmission system should include communications facilities to transmit, relay and collect data from a hydrological observing system and to distribute processed data to users.

[D.1.4.] 2.2

A hydrological data transmission plan should include provision for sensor interfacing, communications equipment, data formatting, operating personnel and operation procedures.

[D.1.4.] 2.2.1

The hydrological data transmission plan should be reviewed and revised, as needed.

[D.1.4.] 3

#### **Organization of data transmission**

[D.1.4.] 3.1

Each Member should ensure that national hydrological data transmission facilities meet both national needs and international requirements agreed upon on the basis of bilateral or multilateral agreement.

[D.1.4.] 3.2

Each Member should ensure that the technical characteristics and operational methods are compatible with regional telecommunication networks and associated plans.

[D.1.4.] 3.3

Each Member should ensure the collection of hydrological and related meteorological observational data from its own territory and ensure reception of such data from one or more other Members, if required, on the basis of bilateral or multilateral agreement.

[D.1.4.] 3.4

Each Member should ensure distribution of data and resulting processed information to its users and, if required, to other Members, on the basis of bilateral or multilateral agreement.

[D.1.4.] 3.5

Each Member should, according to:

- (a) National needs, establish a communication link between its Hydrological Service(s) and the National Meteorological Centre (NMC);
- (b) International needs for exchange, establish a communication link through the NMC in order to use the GTS.



## CHAPTER D.1.5 WATER QUALITY MONITORING

[D.1.5.] 1

### General

Each Member should establish a water quality monitoring programme according to its national requirements.

NOTE: Detailed guidance on the establishment of a water quality monitoring programme is provided in section XIII of the annex and in the *Manual on Water Quality Monitoring* (WMO-No. 680).

[D.1.5.] 2

### Monitoring programme

The water quality monitoring programme should consist of a number of interrelated components:

- (a) Water quality legislation and policies;
- (b) Programme objectives;
- (c) Programme design;
- (d) Field activities;
- (e) Laboratory activities;
- (f) Data management;
- (g) Data analysis;
- (h) Quality assurance programme;
- (i) Interpretation and report generation;
- (j) Information utilization and decision-making.

[D.1.5.] 3

### Monitoring objectives

The objectives of a water quality monitoring programme should be stated in terms of the “products” which the programme will deliver and should be directly linked to the responsibilities in the current legislation, policies and priorities as well as to the existing infrastructure and resources.

[D.1.5.] 4

### Network design

NOTE: Water quality monitoring can be adequately accomplished through the operation of a network of strategically located long-term stations (basic network) supplemented as necessary by periodic short-term surveys of intermediate stations

(secondary network) including the monitoring of accidental pollution of water bodies.

**The network design shall be based on the monitoring objectives of the programme and shall be coordinated with the existing hydrological network.**

[D.1.5.] 5

### Water quality parameters

[D.1.5.] 5.1

The selection of water quality parameters to be monitored in rivers, lakes/reservoirs and groundwaters should be based on previous pilot studies. The basic parameters are listed in the table in section XIII of the annex.

[D.1.5.] 5.2

Special precautions should be taken to preserve the integrity of samples during storage and transportation for laboratory analysis.

NOTE: The quality of certain parameters including electrical conductivity, pH, dissolved oxygen, temperature, colour, turbidity and transparency may change during storage and should be measured in situ or in the field as soon as possible after sampling.

[D.1.5.] 6

### Collection of water samples

[D.1.5.] 6.1

The type of surface water sample to be collected should be determined by:

- (a) The objectives of the programme, including the parameters of interest and the precision and accuracy needed;
- (b) The characteristics of the system being studied, including the flow regime, tributaries, groundwater infiltration, homogeneity of the water body, climatic conditions, anthropogenic inputs, and the aquatic life present.

NOTES:

- (a) Three types of water samples are defined: grab or discrete; depth integrated grab; and composite.

- (b) General sampling guidelines are given in section XIII, XIII-3.2 of the annex.

[D.1.5.] 6.2

Groundwater samples should be taken from pumped wells or from flowing artesian wells. In open wells or in cases where samples are required from specific depths, small diameter grab samplers should be used.

[D.1.5.] 6.3

When collecting samples for radioactivity measurements precautions should be taken to avoid absorption on the walls of the container or on suspended matter.

NOTE: Acceptable container materials include polypropylene, polyethylene or teflon.

[D.1.5.] 6.4

Sampling for biological analysis requires specific samplers and procedures and should follow the recommendations given in section XIII, XIII-4.3 of the annex.

[D.1.5.] 6.5

Guidelines on the collection of samples for atmospheric deposition measurement are given in section XIII, XIII-4.4 of the annex.

[D.1.5.] 6.6

Guidelines on the collection of samples for sediment measurement are given in the *Manual on Sediment Management and Measurement* (WMO-No. 948).

[D.1.5.] 6.7

For sampling sites located on a non-homogeneous reach of a river or stream, samples should be collected on a cross-section of the channel at a specified number of horizontal points and depths.

[D.1.5.] 6.8

The frequency of sampling should be based on the variability of the data, the concentrations to be measured and the changes to be detected.

[D.1.5.] 7

**Field safety**

Field personnel should be trained to recognize potential hazardous situations and to take measures necessary to minimize hazards.

NOTE: Apart from physical hazards, the water being sampled may contain chemical and/or biological substances which may be harmful and contact with the skin should be avoided. Special precautions will be required in the handling of sewerage and industrial effluents.

## D.2 — METEOROLOGICAL SERVICES FOR HYDROLOGY

[D.2.] 1

### General

Each Member should ensure that the dissemination of meteorological information necessary to meet the requirements of hydrology is reliable, regular and adapted to expressed and established requirements.

[D.2.] 2

### Meteorological observations for hydrological purposes

[D.2.] 2.1

Each Member should disseminate those meteorological observations from stations which are required for the analysis of the response of a drainage basin to changes in meteorological conditions.

[D.2.] 2.2

Meteorological observations for hydrological purposes from such stations should concern one or several of the meteorological elements listed in [D.1.2.] 1.2, as required.

[D.2.] 2.3

The precision of observation of meteorological elements for hydrological purposes and the reporting interval for hydrological forecasting purposes should be as shown in the table below.

[D.2.] 3

### Meteorological forecasts and warnings for hydrological purposes

[D.2.] 3.1

Members should ensure that meteorological forecasts and warnings for hydrological purposes are made available routinely to the hydrological forecaster as required.

[D.2.] 3.2

The programme on forecasts and warnings for hydrology should include:

- (a) The type of meteorological information listed in section [D.2.] 2.3. The forecasts should be regular and

<i>Element</i>	<i>Precision</i>	<i>Reporting interval for hydrological forecasting purposes</i>
(a) Precipitation – amount and form*	± 2 mm below 40 mm ± 5% above 40 mm	6 hours**
(b) Snow depth	± 2 cm below 20 cm ± 10% above 20 cm	Daily
(c) Water equivalent of snow cover	± 2 cm below 20 cm ± 10% above 20 cm	Daily
(d) Air temperature	± 0.1°C	6 hours
(e) Wet-bulb temperature	± 0.1°C	6 hours
(f) Net radiation	±0.4 MJ/m <sup>2</sup> d below 8MJ/m <sup>2</sup> ±5% above 8MJ/m <sup>2</sup> d	Daily
(g) Pan evaporation	±0.5 mm	Daily
(h) Surface temperature – snow	± 0.1°C	Daily
(i) Temperature profiles – snow	± 0.1°C	Daily
(j) Wind: speed direction	± 10% } ± 10°C }	6 hours
(k) Sunshine duration	± 0.1 hour	Daily
(l) Relative humidity	± 1%	6 hours

\* In some locations it will be necessary to distinguish the form of precipitation (liquid or solid).

\*\* The reporting interval in flash flood basins is often required to be two hours or less; in other locations, daily values may suffice.

detailed, specifying to the greatest possible extent local and regional variations;

- (b) The following forecasts:
  - (i) Quantitative precipitation forecasts (QPF) for periods of up to 72 hours;
  - (ii) Air temperature, humidity, dew point, wind and sky conditions for up to five days;
  - (iii) Wind speed and directions for 24 hours or more;
- (c) Warnings of hazardous weather conditions, particularly in the following cases:
  - (i) Heavy precipitation (amount and intensity);
  - (ii) Sudden and persistent changes in temperature to above or below freezing;
  - (iii) Strong winds.

[D.2.] 4

### **Publication and dissemination of climatological data for hydrological purposes**

[D.2.] 4.1

Each Member should publish annually its climatological data for hydrological purposes in addition to those published as climatological data.

[D.2.] 4.2

The publication of climatological data for hydrological purposes should conform with [B.1.] 4.1.1, [B.1.] 5.2.2,

[B.1.] 5.2.3 and [B.1.] 5.2.4 of the *Technical Regulations*, concerning the publication of climatological data, except that these data should be grouped according to main drainage basins.

NOTE: For convenience [B.1.] 4.1.1, [B.1.] 5.2.2, [B.1.] 5.2.3 and [B.1.] 5.2.4 are given in the appendix.

[D.2.] 4.3

Climatological data published or disseminated for hydrological purposes should include frequencies, sums or averages, whichever applicable, of the following elements and for time units as indicated in [B.1.] 4.1.1, [B.1.] 4.2.1 and [B.1.] 4.2.2 of the *Technical Regulations*:

- (a) Air temperature;
- (b) Relative humidity;
- (c) Wind speed and direction;
- (d) Precipitation (amount and intensity);
- (e) Solar radiation;
- (f) Snow cover;
- (g) Pan evaporation;
- (h) Wet-bulb temperature;
- (i) Sunshine duration.

NOTE: For convenience [B.1.] 4.1.1, [B.1.] 4.2.1 and [B.1.] 4.2.2 are given in the appendix.

## APPENDIX

(See [D.2.] 4.2 and 4.3)

### CLIMATOLOGICAL STATISTICS

*This is reproduced from Volume I, Chapter [B.1.].*

[B.1.] 4.1

#### Time units

[B.1.] 4.1.1

The time units used in processing climatological data should be selected from the following:

- (a) The Gregorian calendar year;
- (b) The months of this calendar;
- (c) The mean solar day, from midnight to midnight, according to the zonal time or the mean solar time of the station, when the climatological data permit.

[B.1.] 4.2

#### Climatological frequencies, sums and averages

[B.1.] 4.2.1

Frequencies, sums or averages, whichever applicable, of the observations of a meteorological element at a fixed time of the day or of extreme values for the day should be computed, either for individual time units or for a sequence of recurring time units (e.g. ten successive Januaries, etc.) using international time designation.

[B.1.] 4.2.2

Frequencies, sums or averages, whichever applicable, of all or most of the following data from a selection of climatological stations should be computed for each month:

- (a) Atmospheric pressure at fixed times at the reference level appropriate to the station, as indicated in [B.1.] 5.2.2.2 (b);
- (b) Air temperature at fixed times;
- (c) Daily air temperature extremes;
- (d) Relative humidity at fixed times;
- (e) Vapour pressure at fixed times;
- (f) Wind speed at fixed times, and for fixed periods;
- (g) Wind direction at fixed times;
- (h) Cloud amount at fixed times;

- (i) Amounts of precipitation for fixed periods;
- (j) Duration of bright sunshine for fixed periods.

[B.1.] 5.2.2

The general information contained in annual climatological reports should consist of:

[B.1.] 5.2.2.1

A statement giving:

- (a) The standards of time used;
- (b) The types of instrument used;
- (c) The methods of applying corrections;
- (d) The methods in which conventional means are computed;
- (e) The times at which extreme temperatures are read.

[B.1.] 5.2.2.2

A list for each station giving:

- (a) Name and geographical coordinates;
- (b) The altitude of the reference levels for station pressure;
- (c) The heights of the thermometer bulb, the anemometer head and the rim of the raingauge above ground level.

NOTE: Model tables for climatological summaries are given in the *Guide to Climatological Practices* (WMO-No. 100).

[B.1.] 5.2.3

If the main language of a publication is not English, French, Russian or Spanish, all headings of tables should be in one of these official languages, or in internationally recognized symbols or letters.

NOTE: Although Arabic and Chinese are official languages of WMO, Congress has not yet approved their use in all aspects of the work of WMO.

[B.1.] 5.2.4

Each Member should publish or make available on a national and a regional basis at least the following radiation data:

- (a) For principal radiation stations, hourly totals of global solar radiation and of sky radiation [see *Technical Regulations*, Volume I, [B.1.] 5.2.4 (a)];
- (b) For ordinary radiation stations, daily totals of global solar radiation [see *Technical Regulations*, Volume I, [B.1.] 5.2.4 (b)].

## D.3 — HYDROLOGICAL BIBLIOGRAPHY AND PUBLICATIONS

[D.3.] 1

### **Hydrological documents and abstracts**

[D.3.] 1.1

#### **General form of hydrological documents and abstracts**

[D.3.] 1.1.1

Official publications which give the results of studies in hydrology and which may be distributed internationally should include an abstract in at least one of the following official languages: English, French, Russian or Spanish.

NOTE: Although Arabic and Chinese are official languages of WMO, Congress has not yet approved their use in all aspects of the work of WMO.

[D.3.] 1.1.2

The International Organization for Standardization (ISO) system of Cyrillic transliteration should be used in all hydrological documents and publications for international use.

[D.3.] 1.1.3

Films, perforated or not, used for making microfilm copies of hydrological documents should have a width of 16, 35 or 70 mm.

[D.3.] 1.2

### **Classification of hydrological documents and abstracts**

Official hydrological documents, abstracts and bibliographies intended for international dissemination should be classified in conformity with and should bear the relevant number of the Universal Decimal Classification (UDC), Section 556, as given in the appendix.

[D.3.] 1.3

### **Preparation of catalogues of hydrological documents**

[D.3.] 1.3.1

The catalogue cards prepared by Members and intended for international dissemination should contain the relevant UDC numbers of the hydrological documents, books, pamphlets and periodicals to which the cards pertain.

[D.3.] 1.3.2

Catalogue cards prepared by members for books, pamphlets and periodicals should contain the following information: the UDC indexes, the name or names of the author(s), the title and its translation where applicable, the name of the editor, the number of the edition, the volume number or year of publication or of reprinting (in the case of a series of periodicals), the fascicle or issue number, place of publication, publisher and date of publication, the number of volumes of a single work, format, pagination of the book or article, illustrations and plates, collection or series to which the work belongs, a note on the existence of an author's abstract, if any, and any amplification of the title.



## APPENDIX

(See [D.3.] 1.2)

### UNIVERSAL DECIMAL CLASSIFICATION FOR HYDROLOGY

NOTE: The Universal Decimal Classification (UDC) is internationally sponsored by the International Federation for Documentation (IFD), with whose permission the scheme for general hydrology (UDC 556), as well as the major classes and secondary headings applicable to hydrology, are reproduced here. The structure of UDC and explanations for notations used therein are given in *Universal Decimal Classification*, Medium English Edition, FID No. 571, 1985. The list below will be updated as soon as the new edition of the UDC is published.

#### MAJOR CLASSES AND SECONDARY HEADINGS APPLICABLE TO HYDROLOGY

- 0 GENERALITIES
  
- 3 SOCIAL SCIENCES
  - 31 Sociology. Demography. Statistics
  - 32 Political Science
  - 33 Economics
  - 34 Law
  - 35 Public Administration
  - 37 Education
  
- 5 MATHEMATICS AND NATURAL SCIENCES
  - 51 Mathematics
    - 519.2 Probability and mathematical statistics
  - 52 Astronomy. Astrophysics. Space Research. Geodesy
    - 520 Instruments and techniques
    - 527 Navigation
    - 528 Geodesy. Surveying. Photogrammetry. Remote sensing. Cartography
  - 53 Physics
    - 531 Mechanics
      - 532 Fluid mechanics, Hydromechanics
      - 533 Gas mechanics
      - 536 Heat. Thermodynamics
      - 539 Physical nature of matter (Nuclear physics)
    - 54 Chemistry
      - 546 Inorganic chemistry
      - 547 Organic chemistry
      - 548 Crystallography
    - 55 Geology, Meteorology. Hydrology
    - 550 Collateral science. Geophysics
      - .3 Geophysics
        - .34 Seismology
        - .37 Geoelectricity
        - .38 Geomagnetism
    - 551 General geology. Meteorology. Climatology. Stratigraphy
      - .2 Interior geodynamics
      - .3 Exterior geodynamics
        - .32 Glaciology
        - .33 Glacial geology
        - .34 Frost action on rocks and soil
      - .4 Geomorphology
      - .46 Physical oceanography
      - .5 Meteorology\*

\* The complete scheme of UDC 551.5 is reproduced in WMO *Technical Regulations*, Volume I, Appendix C.

.7	Historical geology. Stratigraphy
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552	Petrology. Petrography
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556	Hydrosphere. Water (in general). General hydrology
.1	Hydrological cycle, properties and conditions. Global water balance
.3	Groundwater hydrology. Geohydrology. Hydrogeology
.5	Surface water hydrology. Land hydrology
56	Paleontology
57	Biology
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62	Engineering
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.22	Water power. Utilization of hydraulic energy
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625	Railway, highway engineering
626	Hydraulic engineering
627	River and harbour engineering
628	Public health engineering
629	Transport engineering
63	Agriculture and Related Sciences and Techniques
630	Forestry
633	Field crops and their production
634	Horticulture generally
635	Garden plants. Gardening
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65	Management. Administration. Organization
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.3	Data processing equipment
.5	Automatic control engineering
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71	Physical Planning. Landscape, etc.
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## 8 LANGUAGES AND LITERATURE

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91	Geography
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### SECTION 556 – HYDROSPHERE. WATER (IN GENERAL)

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	Comprehensive works on surface waters and groundwater
→532	Fluid mechanics. Hydraulics
551.4	Geomorphological aspects
551.46	Oceanographic aspects
621.6	Fluid storage and distribution (engineering)
66/627	Hydraulic construction works. Waterways, etc.
628.1/3	Water supply, drainage, and waste disposal
556.01	Theory. Principles of research and investigation
.011	Theoretical principles
.012	Research, methodology, requirements, etc.
.013	Theoretical investigation: use of models, etc. Cf. 556.072 Models
.014	Experimental (laboratory and field) investigation

- 556.02 Practical work: organization, programmes, projects, etc.
  - Details of organization :061...
  - Organization and management techniques by :65....
  - .023 Laboratories and laboratory work
  - .024 Stations and field work generally
  - .025 Services and networks, including network design
  - .028 Representative and experimental basins
- 556.04 Observation(s), data and records
  - .042 Observation methods
  - .043 Data handling: collection, processing, and dissemination
  - .044 Data, observational data (on specific hydrological phenomena)
  - .045 Records
  - .047 Hydrological analyses
  - .048 Hydrological computation. Coefficients, etc.
- 556.06 Hydrological forecasting and forecasts
  - "32" Seasonal
  - (1/9) Regional
- 556.07 Equipment, installations and apparatus for hydrological work
  - .072 Models, analogies, etc. Subdivide as 53.072
  - .078 Special apparatus and equipment for study of hydrological phenomena, e.g. 556.132.8.078
  - Evaporation pans
- 556.08 Measurement: principles and instruments. Subdivide as 53.08, e.g.
  - .082 Principles of measurement and of measuring instruments
  - .084 Instruments: design, construction, and components
  - .085 Indicators, Scales, etc.
  - .088 Measurement errors, correction, and evaluation

556.1 HYDROLOGICAL CYCLE, PROPERTIES AND CONDITIONS. GLOBAL WATER BALANCE

- 556.11 Water properties
  - .113 Physical properties of water
    - .2 Further details: 53...
    - .3 Turbidity
    - .4 Colour
  - .114 Chemical properties of water
    - Further details: 54..., e.g.
      - :541.132 Electrolytic dissociation and pH (H-ion concentration)
      - :543.242 Oxidation-reduction analysis. Redox potential
      - :543.319 Alkalinity
    - .2 Dissolved gases
    - .3 Hardness of water
    - .4 Taste and odour
      - .42 Taste of water
      - .44 Odour of water
    - .5 Salinity
    - .6 Element and inorganic content (of water)
      - Subdivide as 546, e.g.
        - .6.027 Isotope content (generally)
        - .611\*3 Tritium (3H) content
        - .679 Radioactive elements (generally)
          - Cf. 556.388; 556.535.8; 556.555.8
    - .7 Organic chemical content
      - Subdivide as 547... (or :547)
  - .115 Biological and microbiological properties of water
    - Further details: 57/59, e.g.
      - :579.8 Bacteria, micro-organisms
      - :582 Plants, flora
      - :592/599 Animals, fauna
- 556.12 Precipitation: rainfall, snow, etc. (as element in the hydrological cycle)
  - 551.57 Aqueous vapour, precipitation, and hydrometeors (meteorology)
    - "32" Seasonal variations
    - "45" Annual variations
    - (1/9) Geographical, areal distribution
  - .04 Observations, data and records, e.g. snow and glacier melt rates
  - .121 Amount and duration of precipitation
    - .2 Mean or average
    - .3 Maximum
    - .4 Minimum
    - .6 Intensity
    - .7 Duration

- .8 Relation between duration and intensity
- .123 Rainfall. Subdivide as 556.121 and use "32" and "45" for seasonal and annual variations
- .124 Snow and ice. Snowpack. Glacier
  - 551.32/.34
- .1 Amount and duration. Subdivide as 556.121
- .2 Snow cover: distribution and water equivalent
- .3 Melting of snow: rate, relationships, etc.
- .4 Melting of glaciers
- 556.13 Evaporation, evapotranspiration and transpiration (in the hydrological cycle). Cf. 551.571/.574
  - .131 Total evaporation. Evapotranspiration
    - .1 Computation and determination: methods and equipment
    - .11 Water balance methods
      - .112 Evaporimetry and evaporimeters
      - .114 Lysimetry and lysimeters
      - .116 Soil-moisture and groundwater level variations
    - .12 Energy balance methods
    - .13 Vapour flux, turbulent diffusion
    - .14 Moisture advection
    - .18 Empirical formula methods of computation
  - .2 Amounts of total evaporation
  - .3 Condensation of the Earth's surface
  - .5 Evaporation control → 556.18
  - .132 Evaporation
    - .2 Evaporation from water bodies
      - .28 Evaporation from ponds
    - .4 Evaporation from snow and ice former number: 556.134
    - .6 Evaporation from land (solid, fields, forests) former number: 556.133
    - .8 Pan evaporation
- 556.14 Infiltration (as element in the hydrological cycle)
  - .142 Soil moisture → 631.432 (Agriculture)
  - .143 Groundwater storage → 556.32 (Vertical distribution)
- 556.15 Water storage (as element in the hydrological cycle)
  - .152 Surface detention
  - .153 Channel (and bank) storage
    - .5 Bank storage
  - .155 Lake and reservoir storage → 627.81 Dams
  - .157 Valley storage
- 556.16 Runoff
  - "32" Seasonal
  - "45" Annual
    - .01 Theory of runoff
      - .044 Depth, runoff depth
      - .045 Streamflow records
      - .047 Hydrographs, unit hydrographs
      - .048 Computation and coefficients
    - .06 Forecasting, forecasts
  - .161 Rainfall–runoff relation. Runoff factors
  - .162 Distribution (and frequency). Use "32", "45" and (1/9)
  - .164 Surface runoff. Overland flow
  - .165 Normal runoff and its computation
  - .166 Maximum runoff. Floods and flood runoff
    - 627.51
      - "321" Spring (snow-melt)
      - "324" Winter
    - .2 Storm floods
    - .4 Flash floods
  - .167 Minimum runoff. Base flow. Dry-weather flow
    - .2 Base flow
    - .6 Drying-up, drought
  - .168 Underground runoff → 556.332.2 Aquifers
- 556.18 Water management. Applied hydrology. Human control of hydrological conditions
  - .182 Divide by: 626/627, :628..., :631.6..., etc.
- .182 Conjunctive use of surface and groundwater resources

## 556.3 GROUNDWATER HYDROLOGY. GEOHYDROLOGY. HYDROGEOLOGY

- 550.8 Geological exploration methods, prospecting
- 551.44 Speleology, subterranean waters, etc.
- .01 Theory of groundwater, principles of investigation and research

- .02 Practical work organization: projects, laboratories, stations, services, and networks
- .04 Observation(s), data, and records
- .06 Forecasting and forecasts
- .07 Equipment, apparatus, models, etc.
- .08 Measurement: principles and instruments
- 556.31 Properties of groundwater. Subdivide as 556.11, e.g.
  - .313 Physical properties: temperature, colour, turbidity, etc.
  - .314 Chemical and physio-chemical properties: hardness, taste and odour, salinity, chemical content
  - .315 Biological and microbiological properties: bacteria, plants, animals
- 556.32 Subterranean (underground) water: vertical distribution
  - .322 Zone of aeration. Suspended water. Vadose water
    - .2 Soil water
    - .4 Pellicular and gravitational water
    - .6 Capillary water
  - .324 Zone of saturation. Groundwater (in restricted sense)
- 556.33 Aquifers. Water-bearing strata
  - .332 Unconfined (phreatic) aquifers
    - .2 Storage capacity: inflow and outflow
    - .4 Permeability of rock formations
      - .04 Observations and tests, data, records, analyses
        - .042 Pumping tests
        - .048 Storage coefficient. Specific yield
      - .41 Impermeable, not containing water. Aquifuges
      - .42 Impermeable, containing water. Aquicludes
      - .43 Slowly permeable water-bearing strata
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      - .46 Karst formations → 551.435.8 Geomorphology of karst
    - .5 Water table. Phreatic surface
    - .52 Fluctuations (or water table)
      - "32" Seasonal fluctuations
        - :551.466.7 Tides
        - :550.348 Seismic disturbances, tremors, earthquakes
        - :551.54 Atmospheric pressure effects
        - :556.53 Rivers and streams (as fluctuation factors)
    - .6 Recharge
      - .62 Natural recharge and its sources
        - :556.12 Precipitation, rainfall, etc.
        - :556.168 Underground runoff
        - :556.55 Lakes and reservoirs
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      - .629 Other sources of natural recharge
      - .63 Artificial recharge and its methods → 628.112.2/.3
        - .632 Pits and shafts
        - .633 Spreading
        - .634 Injection wells
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        - .639 Other methods of artificial recharge
      - .7 Seawater intrusion → 556.388 Pollution
        - .72 Freshwater-saltwater interface
        - .78 Methods of prevention (of seawater intrusion)
  - .334 Confined (artesian) aquifers
    - Subdivide as 556.332 where applicable, adding:
      - .3 Compressibility
      - .5 Piezometric surface
    - .336 Perched aquifers. Subdivide as 556.332 where applicable
- 556.34 Groundwater flow. Well hydraulics
  - 532.5 Hydrodynamics, fluid flow
  - 628.112 Wells (water supply)
    - .042 Observation wells
  - .342 Flow rate. Velocity. Gradient
    - .2 Darcy's law
      - 532.546 Flow in porous media
  - .343 Flow to wells. Drawdown
    - .2 Radial flow
      - .22 Steady flow
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    - .4 Interference of wells
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- 556.36 Springs Cf. 556.182 → 628.112.1 Catchment

- .362 Depression springs
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- .364 Artesian springs
- .366 Fracture springs
- .367 Intermittent springs
- .368 Volcanic springs
- 553.7 Mineral springs
- 556.38 Groundwater basins. Groundwater management
  - Cf. 556.182 Conjunctive use of groundwater and surface water
  - .02 Practical work organization: projects, networks, etc.
  - .382 Safe yield
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  - .388 Pollution (of groundwater). Protective measures
    - 556.332.7 Sea-water intrusion
    - 504.43 Groundwater environment
      - .2 Protection of intake areas and sources
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- 556.5 SURFACE WATER HYDROLOGY. LAND HYDROLOGY
  - 551.435 Geomorphology of surface waters
  - .01 Theory, principles of investigation and research
  - .02 Practical work organization: stations, networks, etc.
  - .028 Representative and experimental basins
  - .04 Observations(s), data and records
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  - .07 Equipment, apparatus, models
  - .072 Models. Subdivide as 53.072
  - .08 Measurement: principles and instruments. Subdivide as 53.08
- 556.51 Drainage or catchment areas, basins. River basins. Watersheds (Amer.)
  - 551.435.164 Geomorphology: catchment basins
  - .028 Representative and experimental basins
  - .512 Water balance of drainage basins
  - .513 Area of drainage basins
  - .514 Shape of drainage basins
  - .515 Slope of drainage basins
  - .516 Stream density
- 556.52 River systems. Potamology (general description)
  - .522 Classification. Order of stream
  - .523 Large streams
  - .524 Tributaries
- 556.53 Rivers, streams and canals
  - .531 Water properties (in rivers). Subdivide as 556.11, e.g.
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    - .4 Chemical properties, incl. hardness, taste, and odour
    - .5 Biological and microbiological properties
  - .532 Water balance (of perennial streams)
    - :556.16 Runoff
  - .535 River regimes
    - .2 Level
    - .3 Discharge
    - .4 Thermal regime
    - .5 Ice regime → 551.326.83 Ice on streams
    - .6 Sediment transport → 532.584 Hydrodynamics
    - .8 Pollution (of rivers) → 504.453 Fluvial environment, rivers, streams
  - .536 Hydraulics, hydrodynamics of rivers and streams
    - Fluvial hydraulics → 532.5 Hydrodynamics
      - .2 Currents, river currents
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  - .537 Channel and bank formation (only hydrological aspects)
    - 551.435.1 Geomorphology of rivers
    - 627.4 River training
  - .538 Intermittent or ephemeral streams
    - .1/7 Subdivide as 556.531/.537 where applicable
- 556.54 River mouths. Estuaries. Deltas. Subdivide as 556.53 where applicable
  - 551.435.126 Geomorphology of deltas
  - 551.468.6 Estuaries. Exchange of sweet and sea water
  - .541 Water properties in river mouths and estuaries. Subdivide as 556.11
  - .542 Water balance (in river mouths and estuaries)
  - .545 Estuarine regimes, pollution. Problems of exchange between fresh and saline water, mixing, resulting in brackish water

- 504.454 Fluvio-marine environment. River mouths.
- Estuaries
- .546 Estuarine hydraulics and hydrodynamics
- 556.55 Lakes, reservoirs and ponds. Limnology
- 551.435.38 Geomorphology of lake basins
- (211) Polar
- (212) Temperate
- (213) Tropical and subtropical
- .551 Water properties in lakes, reservoirs, and ponds. Subdivide as 556.11
- .552 Water balance of lakes
- .555 Lake regimes
- .2 Level
- .3 Inflow and outflow
- .4 Thermal regime. Thermal stratification
- .41 Epilimnion
- .42 Metalimnion. Thermocline
- .43 Hypolimnion
- .5 Ice regimes → 551.326.85 Ice on lakes
- .6 Sedimentation and silting (in lakes)
- .7 Chemical stratification
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- 504.455 Freshwater environment, lakes, reservoirs and ponds
- .556 Hydraulics, hydrodynamics of lakes
- 532.5 Hydrodynamics
- .2 Currents
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- .4 Seiches
- .5 Wind influences. Wind set-up
- Cf. 551.556.8 (Meteorology)
- .557 Lake shores and their alteration
- 551.435.3 Geomorphology of lakes
- 627.8 Dams
- 556.56 Swamps and marshes
- :626.86 Drainage of swamps
- 551.435.1 Geomorphology of swamps
- .561 Water properties in swamps. Subdivide as 556.11
- .562 Water balance of swamps
- .565 Swamp regimes. Pollution, etc. → Freshwater environment, swamps
- .566 Hydraulics, hydrodynamics of swamps
- 532.5 Hydrodynamics



**A N N E X**  
**HYDROLOGICAL INSTRUMENTS AND METHODS OF OBSERVATION**

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## DEFINITIONS

NOTE: The following terms, when used in the annex of the *Technical Regulations*, Volume III — Hydrology, have the meaning given below. Those terms which have already been defined at the beginning of the *Technical Regulations*, Volume III — Hydrology, have the meaning given below. Those terms which have already been defined at the beginning of the *Technical Regulations* are not repeated here.

**Acidity.** The quantitative capacity of aqueous media to react with hydroxyl ions.

**Adsorption.** The surface retention of solid, liquid or gas molecules, atoms or ions by a solid or liquid.

**Air line correction.** Depth correction to a sounding line measurement for that portion of the line which is above the water surface when the flow deflects the sounding line downstream.

**Arithmetic mean.** Sum of values/variates divided by their number/by the number of occurrences.

**Baffle.** A wall or blocks placed in the stream to dissipate energy or to cause improved velocity distribution.

**Bed profile (of a stream).** The shape of the bed in a vertical plane; it may be longitudinal or transversal.

**Benchmark.** A permanent mark, natural or artificial, at a known elevation in relation to an adopted datum.

**Blank.** A sample of distilled or deionized water free of analytes of interest.

**Bottom sediment.** Those sediments which make up the bed of a body of running or still water.

**Broad-crested weir.** A weir of sufficient breadth (i.e. the crest dimension in the direction of the flow) such that critical flow occurs on the crest of the weir.

**Calibration (rating).** Experimental determination of the relationship between the quantity to be measured and the indication of the instrument, device or process which measures it.

**Calibration (rating) tank.** A tank containing still liquid (water) through which the current meter is moved at a constant velocity for calibrating the meter.

**Celerity.** Speed of propagation of a wave.

**Confidence interval.** The interval which includes the true value with a prescribed probability and which is a function of the statistics of the sample.

**Confidence level.** The probability that the confidence interval includes the true value.

**Confluence.** Joining, or the place of junction, of two or more streams.

**Constant-rate injection method.** A method of measuring the discharge in which a tracer of known concentration is injected at a constant and known rate at one cross-section and its dilution is measured at another section downstream where complete mixing has taken place.

**Contracted weir.** A weir having a crest that does not extend across the whole channel width.

**Control.** The physical properties of a channel, natural and artificial, which determine the relationship between stage and discharge at a location in the channel.

**Control section of a weir or flume.** The section which induces critical flow.

**Cosmic-ray-produced nuclides.** Short-lived radioisotopes such as tritium, beryllium-7 and carbon-14 formed by the continuous "rain" of electrons and nuclei of atoms from space interacting with certain atmospheric and terrestrial elements.

**Crest.** The line or area defining the top of the weir.

**Critical depth.** The depth of water flowing in an open channel under conditions of critical flow.

**Critical flow.** Flow in which Froude number equals unity. Under this condition the celerity of small disturbances equals the mean flow velocity.

**Critical velocity.** (1) Velocity at critical flow in a channel; (2) Velocity at which flow changes from subcritical to supercritical, or vice versa.

**Cross-section.** Section of a stream at right angles to the main (average) direction of flow.

**Current meter.** Instrument for measuring the velocity of water at a point.

**Current meter, cup type.** A current meter whose rotor is composed of a wheel fitted with cups turning on a vertical axis.

**Current meter, propeller type.** A current meter the rotor of which is a propeller rotating around an axis parallel to the flow.

**Dead water.** Water in a state of slow or no circulation.

**Density current.** The phenomenon of gravity flow of a liquid relative to another liquid, or of relative flow within a liquid medium due to difference in density.

**Detection limit.** The smallest concentration of a substance which can be reported as present with a specified degree of precision and accuracy by a specific analytical method.

**Dilution method.** A method of determining the discharge of a stream by measuring the degree of dilution by the flowing water of an added tracer solution.

**Double float.** A body of slightly negative buoyancy which moves with the stream at a known depth and whose position is indicated by a small surface float from which it is suspended.

**Drag.** Force exerted by a flowing fluid, e.g. water, on an object placed in or adjacent to the fluid, projected in the direction of flow.

**Drowned (submerged) weir.** A weir in which the upstream water level is affected by the downstream water level.

**Duplicate samples.** Obtained by dividing one sample into two or more identical subsamples.

**Echo sounder.** An instrument using the reflection of an acoustic signal from the bed to determine the depth.

**Error.** The difference between the result of a measurement and the true value of the quantity measured.

NOTE: This term is also used for the difference between the result of a measurement and the best approximation of the true value (rather than of the true value itself). The best approximation may be a mean of several or of many measurements.

**Fall.** Difference in elevation of water surface between two points of a stream at a given time.

**Filtration.** The process of passing a liquid through a filtering medium for removal of suspended or colloidal matter.

**Float.** Any natural or artificial body which is supported and partly or fully immersed in water, its vertical motion indicating the changes in water level or its horizontal movement indicating the velocity of water at the surface or at various depths.

**Float gauge.** A gauge consisting essentially of a float which rides on the water surface and rises or falls with it, its movement being transmitted to a recording or indicating device.

**Flood plain.** Adjoining nearly level land at the bottom of the valley of a stream flooded only when the streamflow exceeds the water carrying capacity of the channel.

**Flume.** An artificial channel with clearly specified shape and dimensions which may be used for measurement of flow.

**Froude number.** A dimensionless number expressing the ratio of inertia forces to gravity forces:

$$Fr = \frac{v}{\sqrt{g \cdot d}}$$

$v$  = velocity of flow

$g$  = acceleration of gravity

$d$  = average depth of flow

**Geochemistry.** A science that deals with the chemical composition of and chemical changes in the crust of the earth.

**Grab sample.** A sample taken at a selected location, depth and time.

**Head over (on) the weir.** The elevation of the water above the lowest point of the crest, measured at a point upstream.

(The point of measurement depends on the type of weir used.)

**Height of weir.** The height from the upstream-bed to the lowest point of the crest.

**Herbicide.** A chemical agent that destroys specific vegetation.

**Homogeneous.** Uniform in composition.

**Hysteresis (in stage-discharge relation).** The variability of the stage-discharge relation at a gauging station subject to variable slope where, for the same gauge height, the discharge on the rising stage is different from that on the falling stage.

**Injection cross-section.** The cross-section on a stream at which a tracer solution is injected into the flow of water for the purpose of measuring the discharge.

**In situ measurements.** Measurements made directly in the water body.

**Integration (pulse or gulp injection) method.** A method of measuring the discharge in which a known quantity of a tracer is injected over a short time at one cross-section and its dilution is measured at another cross-section downstream where complete mixing has taken place, over a period sufficient to allow all the tracer to pass that cross-section so that the concentration/time relationship of the tracer during the sampling time can be determined.

**Invert.** Lowest part of the cross-section of a channel.

**Kemmerer sampler.** A messenger-operated vertical point sampler for water-suspended sediment.

**Macrophytes.** Large plants.

**Measuring (throated, standing-water) flume.** A flume with side contractions and/or bottom contractions within which the flow changes from subcritical to supercritical, the discharge being determined by the cross-sectional area and velocity of flow at critical depth within the throat.

**Measuring reach.** A reach of open channel selected for measurement of discharge.

**Mixing length.** The minimum length of travel of a tracer after which good mixing is obtained.

**Modular (free) flow.** A flow which is not influenced by the level of water downstream of a measuring device.

**Moving-boat method.** A method of measuring discharge from a boat by traversing the stream along the measuring section whilst continuously measuring velocity, depth and distance travelled.

**Multiple sampler.** An instrument permitting the collection of several water-suspended sediment samples of equal or different volumes at each site, simultaneously.

**Nappe.** The sheet of water flowing over the crest of a wall, dam, or weir erected across a stream having an upper and a lower surface.

**Normal distribution (Gaussian distribution).** A mathematically defined, symmetrical, bell-shaped, continuous distribution, traditionally assumed to represent random errors.

**Notch.** A thin-plate weir of any defined shape producing side contractions.

**Periphyton.** The association of aquatic organisms attached or clinging to rooted plants above the bottom.

**Pesticide.** A chemical agent that destroys pests.

**Pitot tube.** A tube, one end of which is open and held perpendicular to a liquid stream. The speed of the liquid can be determined from the difference between the impact pressure and the static pressure.

**Plankton.** Organisms of relatively small size, mostly microscopic, which either have relatively small powers of locomotion or drift in the water subject to the action of waves and currents.

**Pumping sampler.** A sampler with which the water-sediment mixture is withdrawn through a pipe or hose, the intake of which is placed at the desired sampling point.

**Radioactivity.** The property possessed by some elements, of spontaneously emitting alpha, beta, gamma rays or neutrons by the disintegration of their nuclei.

**Random error.** That part of the total error which varies in an unpredictable manner in magnitude and in sign when measurements of a given quantity are made under the same conditions.

**Range.** The difference between the lowest and highest values in a set of data.

**Reach.** Length of open channel between two defined cross-sections.

**Rectangular-notch thin-plate weir.** A thin-plate weir with a notch of rectangular shape in the plane perpendicular to the direction of flow.

**Replicate samples (spatial).** Two or more samples taken simultaneously in a given cross-section of the water body under study. They are used for measuring the cross-sectional variations in the water quality parameters.

**Replicate samples (temporal).** Two or more samples taken at the same place sequentially at specified intervals over a specific period of time. They are used to determine the uncertainty in various water quality parameters due to temporal variations.

**Round-nosed horizontal-crest weir.** A weir with rounded upstream corner.

**Sampling cross-section.** The cross-section of a stream at which the dilution of the tracer solution is sampled, observed and directly measured.

**Sampling iron.** An iron frame designed to hold sampling bottles of different sizes.

**Sampling vertical.** A vertical line from the water surface to the bottom along which one or more samples are collected to determine various properties of the water body.

**Sequential composite sample.** A sample obtained either by continuous, constant pumping of water or by mixing equal volumes of water collected at regular time intervals. This sample will indicate an average water quality condition over the period of time of compositing.

**Shifting control.** Control in which there is a change in stage-discharge relation resulting from physical changes in the channel.

**Shipek sampler.** An instrument designed to collect relatively undisturbed samples of bottom surface sediments (also Mini-Shipek).

**Side contraction.**

- (a) The reduction in the width of the nappe downstream of a thin-plate weir due to the inward velocity component at the sides;
- (b) The local reduction in the width of an open channel in a standing wave flume.

**Sounding.** Measuring the depth of water with a line, rod or by other means.

**Sounding line.** A chain or cable with a weight attached to its lower end, used for determining depth of water.

**Sounding rod.** A graduated rigid rod for measuring the depth of water.

**Sounding weight.** A weight of streamlined shape attached to a sounding line or to the suspension of a current meter when observing depth or velocities in streams.

**Spike.** A known chemical substance added in known amounts to a sample.

**Split sample.** A single sample separated into two or more parts such that each part is representative of the original sample.

**Spurious error.** Value known for certain to be in error, e.g. due to human mistakes or instrument malfunction.

**Stable channel.** Channel in which the bed and the sides in the control reach remain sensibly stable over a substantial period of time and in which scour and deposition during the rising and falling stages are inappreciable.

**Standard deviation ( $s_y$ ).** The positive square root of the sum of the squares of the deviations from the arithmetic mean, divided by  $(n - 1)$ ; it is given by:

$$s_y = \left[ \frac{\sum_{i=1}^n (y_i - \bar{y})^2}{n - 1} \right]^{\frac{1}{2}}$$

where  $\bar{y}$  is the arithmetic mean of  $n$  independent measurements of the variable,  $y$ .

**Standard error of estimate ( $S_e$ ).** A measure of the variation or scatter of the observations about a linear regression relation. It is numerically similar to the standard deviation except that the regression relation replaces the mean and  $(n - 1)$  is replaced by  $(n - m)$ :

$$S_e = \left[ \frac{\sum_{i=1}^n (d_i)^2}{n - m} \right]^{\frac{1}{2}}$$

where  $d_i$  is the deviation of an observation from the computed regression value,  $m$  is the number of constants in the regression equation and  $(n - m)$  represents the degrees of freedom in the equation derivation.

**Standing wave.** Wave in which the water surface oscillates vertically between fixed nodes.

**Stilling well.** A well connected with the stream in such a way as to permit the measurement of the stage in relatively still water.

**Subcritical flow.** The flow in which the Froude number is less than unity and surface small disturbances will travel upstream and downstream.

**Subsidence.** Lowering in elevation of a considerable area of land surface, due to the removal of liquid or solid underlying material or removal of soluble material by means of water.

**Subsurface float.** A float with its greatest drag below the surface for measuring subsurface velocities.

**Supercritical flow.** The flow in which the Froude number is greater than unity and small surface disturbances will travel downstream.

**Surface float.** A float with its greatest drag near the surface for measuring surface velocities.

**Suspension cable.** The wire from which the current meter is suspended and possibly incorporating an electrical insulated core.

**Systematic error.** That part of the error which either:

- (a) Remains constant in the course of a number of measurements of a given quantity;
- (b) Varies according to a definite law when the conditions change.

**Teflon.** Polytetrafluoroethylene, a man-made plastic material inert to most chemicals or reagents except molten alkali metals. It is used for laboratory and field equipment.

**Thin-plate weir.** A weir constructed of a vertical thin-plate with a thin crest shaped in such a manner that the nappe springs clear of the crest.

**Throat.** The minimum cross-sectional area within a flume. It may have any shape, e.g. rectangular, trapezoidal, U or any other.

**Tide.** Periodic rise and fall of water in the seas or in large lakes due principally to the gravitational attraction of the moon and the sun.

**Tolerance.** The permissible variation of the specified value of a quantity.

**Tracer.** A substance or material, commonly an ion, compound or radionuclide introduced into a flow system to follow the behaviour of some component of that system; it is necessary for the tracer, which can be observed, to behave in exactly the same fashion as the component to be followed, whose behaviour cannot easily be observed.

**Transducer.** A device which responds to a phenomenon and produces a signal which is a function of one or more characteristics of the phenomenon.

**Triangular-notch (V-notch) thin-plate weir.** A thin-plate weir with two edges symmetrically inclined to the vertical to form a triangular notch in the plane perpendicular to the direction of the flow.

**Triangular-profile (Crump) weir.** A broad-crested weir having a triangular profile in a vertical direction in the direction of flow.

NOTE: This should not be confused with a triangular thin-plate weir.

**True value.** The value which is assumed to characterize a quantity in the conditions which exist at the moment when that quantity is observed (or is the subject of a determination). It is an ideal value which could be known only if all causes of error were eliminated.

**Uncertainty.** The interval within which the true value of a quantity can be expected to lie with a stated probability.

**Undercurrent.** (See *Density current*)

**Unstable channel.** (See *Stable channel*)

**Van Dorn sample.** A messenger-operated water-suspended sediment point sampler used to collect samples at a specified depth. The long axis of the cylinder can be lowered either horizontally or vertically.

**Velocity rod; rod float.** A floating rod weighted at the base so that it travels in an almost vertical position; the immersed portion may be adjustable.

**Viscosity.** Property of a fluid to resist shearing in the presence of velocity gradients. It is usually expressed as a coefficient.

**Wading rod.** A light, hand-held rigid rod graduated for sounding the depth and positioning the current meter for measuring the velocity in shallow streams suitable for wading.

NOTE: This may be used from boats or ice cover at shallow depth.

**Water quality criteria.** Scientific information, e.g. concentration-effect data, used to recommend water quality objectives.

**Water quality objective.** A concentration or a narrative statement describing the water body, which, when met, will protect the intended uses of the water.

**Weighted mean.** The arithmetic mean of a series of results of measurements calculated as the sum of the observations, each one being multiplied by the corresponding normalized weight (the sum of the weights being unity).

**Weir.** An overflow structure which may be used for controlling upstream water level or for measuring discharge or for both.

**Wet line correction.** Depth correction to a sounding line measurement for that portion of the line which is below the water surface when the flow deflects the sounding line downstream.

## I – CALIBRATION OF CURRENT METERS IN STRAIGHT OPEN TANKS

(See [D.1.2.] 3.1.1)

### I-1 **Scope and field of application**

NOTE: The material in this section of the annex is based on ISO 3455 (1976) entitled "Liquid flow measurements in open channels — Calibration of rotating-element current meters in straight open tanks".

This section specifies the procedure to be used for the calibration of current meters in order to conform to the requirements of Technical Regulation [D.1.2.] 3.1 and to meet the requirements for accuracy of measurement of river discharge indicated in Technical Regulation [D.1.2.] 3.6. It also specifies the type of tank and equipment to be used and the method of presenting the results.

NOTE: Detailed guidance on calibration of current meters is given in the *Guide to Hydrological Practices* (WMO-No. 168) and in the *Manual on Stream Gauging* (WMO-No. 519).

### I-2 **Principle of calibration procedure**

The current meter should be drawn through clean still water in a straight tank of uniform cross-section at a number of uniform velocities. Measurements should be made of the speed of the towing carriage and of the rate of revolution of the rotor of the current meter. The two sets of values should be related by equation(s) of which the limits of application should be stated.

### I-3 **Design criteria for calibration stations**

#### I-3.1 **Dimensions of the calibration tank**

NOTE: The dimensions of the tank and the number and the relative positions of current meters in the tank cross-section may affect the test results.

##### I-3.1.1 **Length**

- (a) The total length of a calibration tank should be considered as comprising accelerating, stabilizing, measuring and braking sections.
- (b) The length of the accelerating and braking sections should be compatible with the design of the carriage and the maximum speed at which the current meter is to be towed in the tank. The length required for the braking section is governed by safety requirements.

- (c) The length of the measuring section should be such that the calibration error, which is composed of inaccuracies in the measurement of time, distance covered, and rate of revolution of the rotor, should not exceed the desired tolerance at any velocity.

Example: If times both for distance covered by the carriage and for the revolutions counted are measured to an uncertainty of 0.01 s in order to limit the error in time measurement to 0.1 per cent at the 95 per cent confidence level, the duration of the test should be at least 10 s at maximum speed; if the maximum speed is 6 m/s then the measuring section of the tank would be 60 m long; the total length of the tank would therefore be about 100 m of which about 20 m would be for acceleration and stabilizing and 20 m for braking.

NOTE: Detailed descriptions of several tanks are given in the *Manual on Stream Gauging* (WMO-No. 519).

#### I-3.2 **Rating carriage**

I-3.2.1 In order that the current meter can be moved through the water at constant and accurately measured speeds, the current meter should be suspended from a carriage running on rails or a track.

I-3.2.2 The rails or track should be accurately aligned with the longitudinal axis of the tank and the plane of the rails should be parallel to the surface of the water in the tank.

I-3.2.3 The wheels of the carriage should be free of irregularities to eliminate irregular motion of the carriage and transmission of vibrations to the current meters which could disturb the rating.

NOTE: Two types of carriage are in common usage, namely:

- (a) The towed carriage which is moved along the rails by a cable driven from a constant-speed motor standing apart from the moving carriage. The towed carriage may be lightly constructed with the consequent advantage of high acceleration and quick braking, but the elasticity of the towing cable may cause irregularities in the movement of the carriage;
- (b) The self-propelled carriage which is moved along the rails by an internally mounted motor. The self-propelled carriage will be heavier in construction as it also carries the driving motor.

This results in greater inertia of the carriage and assists in smoothing out the running irregularities of the carriage.

### I-3.3 Measuring equipment

NOTE: The calibration of a current meter requires the simultaneous measurement of the following three quantities:

- (a) The distance covered by the carriage;
- (b) The number of pulses delivered by the current meter;
- (c) The time.

The towing speed is calculated from the simultaneous measurements of distance and time and the rate of revolution of the rotor is obtained by simultaneous measurement of the number of pulses and time.

#### I-3.3.1 Distance

The uncertainty in the distance measurement should not exceed 0.1 per cent at the 95 per cent confidence level.

NOTE: Two of the most common methods are:

- (a) The establishment of markers at regular intervals along the length of the calibration tank which actuate mechanical or optical pulse transmitters fitted to the carriage;
- (b) The use of measuring wheels with mechanical or photo-electric pulse transmitters which are drawn along the track by the carriage.

#### I-3.3.2 Time

The measurement of time should be accurate to within 0.1 per cent at the 95 per cent confidence level.

NOTE: Two of the most common timing methods in use are:

- (a) A clock giving a contact pulse every one or several seconds. These time pulses are usually recorded on a graph or magnetic tape together with the pulses of the rotating element of the current meter and the distances travelled. The time corresponding to an integral number of pulses from the meter is usually determined by interpolation of the time pulse;
- (b) Electronic clocks, capable of measuring fractions of a second, which time and display a preset number of distance intervals and a corresponding number of pulses.

#### I-3.3.3 Current-meter pulses

- (a) The uncertainty in the measurement of rotor revolutions should not exceed 0.1 per cent at the 95 per cent confidence level. The pulses from the current meter should be counted or recorded.
- (b) In determining the number of rotor revolutions in a given time, measurement should be made between identical points on the current-meter pulse.
- (c) When a recording is made, the speed of the recording media should be adjustable so that the interval between the current-meter pulse recordings can be made compatible with the speed recordings of the carriage and the required accuracy of the measurement.

### I-3.4 Ancillary equipment

In order to increase the efficiency of a current meter calibration station, several items of ancillary equipment should be provided:

- (a) Filtering, dosing and scum-removing equipment for maintaining clear water;
- (b) Stilling devices to reduce the reflection of disturbances in the water by the end walls of the tank;
- (c) Means for checking that a cable-suspended meter is properly aligned at the start of a run;
- (d) A thermometer to indicate the temperature of the water in the tank.

NOTE: Measurement of temperature of the water in the tank is needed to determine the existence of density currents in the tank and to compute the viscosity of the lubricants used in the current meter being rated.

## I-4 Calibration procedure

### I-4.1 Instructions for calibration

The instructions for calibration should include:

- (a) The limits of calibration speeds;
- (b) Details of the means of suspension and weights;
- (c) For current meters with oil-filled systems, specifications of the oil used;
- (d) Information concerning the desired calibration documents (equations, calibration diagrams or tables, and units in which the results are to be expressed);
- (e) Any particular requirements, such as calibration "as received" and "after repair".

### I-4.2 Suspension of the current meter

I-4.2.1 Before the current meter is immersed in water, it should be checked for cleanliness, lubrication and mechanical and electrical functioning.

I-4.2.2 The suspension of the current meter should usually be the same as that used during field measurement.

I-4.2.3 The current meter should be placed at a depth below the surface of the water so that surface influence is negligible.

NOTES:

- (a) For a propeller-type current meter, a depth (water level to rotary axis) twice the diameter of the rotary element is generally sufficient.
- (b) A cup-type current meter should be immersed to a depth of at least 0.3 m or one-and-a-half times the height of the rotor, whichever is greater.

I-4.2.4 When several current meters are calibrated at the same time, care should be taken to ensure that there is no mutual interference.

I-4.2.5 A rod-supported current meter should be rigidly attached to the rod so that it is aligned in the direction of travel.

I-4.2.6 A cable-suspended current meter should be aligned in the direction of travel at the start of each run.

I-4.2.7 If the meter is of the type which is capable of swivelling in a vertical and/or horizontal plane, its balance should be checked and, if necessary, adjusted so that it is horizontal and perpendicular to the cross-section before calibration tests are started.

#### I-4.3 Performance of calibration

##### I-4.3.1 Minimum response speed

The minimum response speed should be determined by gradually increasing the carriage velocity from zero until the rotating element revolves at a constant angular velocity.

##### I-4.3.2 Number of calibration points

Measurements should be carried out from the minimum response speed at a sufficient number of towing velocities to enable the calibration of the current meter to be defined accurately.

NOTE: It will generally be necessary to carry out tests at closer velocity intervals at the lower end of the range because the largest errors, expressed as percentages, usually occur in this range.

##### I-4.3.3 Stilling time

The water in the tank should be relatively still before each test run and the waiting period should be chosen so that residual velocities are negligible compared with the next test velocity.

NOTE: The time needed for the water to still depends on the dimensions of the tank, the type of damping device, the previous test velocity, the size and shape of the current meters and of the immersed portion of the suspension equipment.

#### I-5 Presentation of results

##### I-5.1 Calibration diagrams

The calibration points should be entered in a graphic system with the velocity  $v$  as the ordinate and the rate of revolution of the rotor  $n$  as the abscissa.

##### I-5.2 Calibration equations

The calibration form should indicate the equation(s) of the straight line(s) with which the calibration curve roughly

coincides, specifying for each value of  $n$  the interval to which it is applicable, as follows:

$$(a) \quad v = a + bn$$

where:

$v$  is the velocity, in metres per second;  
 $n$  is the number or revolutions of the rotor per second;  
 $a$  and  $b$  are constants determined for each equation;

or

$$(b) \quad v = a + b \frac{N}{t}$$

when it is convenient to show the time  $t$  corresponding to  $N$  total rotor revolutions.

##### I-5.3 Calibration tables

The relation between  $v$  and  $n$  should be presented in tabular form.

NOTE: The velocity can be given for every 0.01 rev s<sup>-1</sup> or for integral numbers of revolutions in a predetermined time interval or corresponding to a predetermined number of revolutions.

##### I-5.4 Calibration documents

In addition to the elements mentioned in I-5.1, I-5.2 and I-5.3, the calibration form should include the following information:

- (a) The name and address of the rating station;
- (b) The date of calibration;
- (c) The calibration number;
- (d) The make and type of current meter;
- (e) The serial number of the current meter and of each rotor;
- (f) Details of the suspension used and weights;
- (g) The position of the current meter in the cross-section of the tank;
- (h) A statement of the minimum speed of response;
- (i) The limits of calibration;
- (j) Any remarks such as "as received" rating or statements of any modifications made to the current meter, such as the fitting of spare parts;
- (k) The water temperature during calibration;
- (l) The viscosity of the bearing oil;
- (m) A statement concerning the accuracy of the rating equation, which should include an assessment of the accuracy of the basic calibration technique;
- (n) The signature of a responsible member of the staff at the calibration station.



## II – WATER-LEVEL MEASURING DEVICES

(See [D.1.2.] 3.1.2)

### II-1 Scope and field of application

NOTES:

- (a) The material in this section of the annex is based on ISO 4373 (1995) entitled "Measurement of liquid flow in open channels — Water-level measuring devices".
- (b) Detailed guidance on water-level measuring devices is given in the *Guide to Hydrological Practices* (WMO-No. 168) and in the *Manual on Stream Gauging* (WMO-No. 519).

This section specifies the functional requirements of:

- (a) A stilling well with intake pipes for float-operated water-level recorders;
- (b) Stage sensing devices;
- (c) Water-level recording devices;

in order to conform with the requirements of Technical Regulation [D.1.2.] 3.1 and to meet the requirements for accuracy of measurement of stages and groundwater levels indicated in Technical Regulation [D.1.2.] 3.5.

### II-2 Stilling well and intakes

#### II-2.1 Stilling well

NOTE: The function of the stilling well is:

- (a) To accommodate the instrument and protect the float system;
- (b) To provide within the well an accurate presentation of the water level in the river;
- (c) To damp out oscillations of the water surface.

II-2.1.1 The well may be placed in the stream bank or in the channel but should not be located in the channel where flow conditions would lead to separation and stagnation effects.

II-2.1.2 The well should not interfere with the flow pattern in the approach channel and, if set in relation to a control, it should be placed in the pool formed by the control but upstream from the area of drawdown at the control.

II-2.1.3 The well should be firmly founded when placed in the bank and firmly anchored when standing in the stream so that it should remain stable at all times.

II-2.1.4 The well and all construction joints of well and intake pipes should be watertight so that water can enter or leave only by the intake itself.

II-2.1.5 The well should be vertical and have sufficient height and depth to allow the float to travel freely the full range of possible water levels.

II-2.1.6 The dimensions of the well should be such as to allow unrestricted operation of all equipment installed in it. Clearance between walls and float should be at least 75 mm and, where two or more floats are used within the well, clearance between them should be at least 150 mm. In silt-laden rivers the well should be large enough to be entered and cleaned.

II-2.1.7 When placed in the bank of the stream, the stilling well should have a watertight bottom to prevent seepage into or leakage out of the chamber.

II-2.1.8 In wells with a watertight bottom, the bottom of the well should be at least 300 mm below the invert of the lowest intake to provide space for sediment storage and to avoid the danger of the float grounding at times of low flow.

II-2.1.9 In cold climates the well should be protected from the formation of ice by the use of well covers, sub-floors, heaters, or oil on the water surface. When oil is used, the oil surface will stand higher than the water level in the stream and a correction is required.

#### II-2.2 Intakes

NOTE: The functions of the intakes to the stilling well are:

- (a) To allow water to enter or leave the stilling well so that the water in the well is maintained at approximately the same elevation as that in the stream under all conditions of flow;
- (b) To limit lag and oscillating effects within the stilling well.

Intakes may take the form of a pipe connecting the well to the river when the well is set back into the bank or a series of holes or slots cut into the well itself when it is set directly into the river. In rivers with a high silt content a well set in the stream may have a hopper-shaped bottom to serve as an intake and also as a means of self-cleansing. Two or more intakes may be installed, at different levels, to ensure operation of the system if one intake becomes blocked.

II-2.2.1 The dimensions of the intakes should be large enough to allow the water level in the well to follow the rise and fall of the river stage without appreciable delay.

II-2.2.2 The dimensions of the intakes should be small enough to damp oscillations caused by wave action or surges.

NOTE: These are conflicting requirements and a suitable balance should be achieved. As a general guide the total cross-sectional area of the intakes should not be less than one per cent of the cross-sectional area of the well.

II-2.2.3 For a stilling well set into a bank the invert of the lowest intake should be at least 150 mm below the lowest anticipated stage and should enter the stilling well at least 300 mm above the well bottom. In cold climates this intake should be below the frost line.

II-2.2.4 Intake pipes should be laid at a constant gradient and on a suitable foundation which will not subside.

II-2.2.5 The intake should be so oriented in the stream that it will sense the true water level. When velocities in the stream at the point of measurement are sufficiently large that the dynamic pressure is of sensible magnitude, the intake should incorporate a static pressure device.

II-2.2.6 Intake pipes more than 20 m long should be provided with an intermediate manhole fitted with internal baffles to act as a silt trap and provide access for cleaning.

II-2.2.7 Means of cleaning the intakes should be provided, either by a flushing system where water under several metres of head can be applied to the stilling well end of the intake by pumping water through the intake or by hand cleaning with rods.

II-2.2.8 Where velocity past the river end of the intake is high, drawdown of the water level should be reduced by attaching a capped and perforated static tube to the river end of the intake and extending it horizontally downstream.

## II-3 Stage sensing devices

### II-3.1 Gauge datum

NOTE: The gauge datum may be a recognized datum, such as mean sea level, or an arbitrary datum plane selected for the convenience of using gauge readings of relatively low, but positive, numbers.

II-3.1.1 If an arbitrary datum plane is used, it should be referred to a benchmark of known elevation above sea level by accurate levelling.

II-3.1.2 The zero of the gauge should be correlated with a national datum through a station benchmark.

II-3.1.3 The station benchmark should be set in a position offering maximum security against disturbance. It should be securely fixed in a concrete block or similar mounting that extends below the ground surface to a level free from disturbance, such as frost or hill creep.

## II-4 Vertical and inclined staff gauges

NOTE: Such gauges comprise a scale marked on or attached to a suitable surface.

### II-4.1 Functional requirements

These gauges should meet the following functional requirements:

- (a) They should be accurate and clearly marked;
- (b) They should be durable and easy to maintain;
- (c) They should be simple to install and use.

### II-4.2 Material

The material of which a gauge is constructed should be durable and should have a low coefficient of expansion.

### II-4.3 Graduation

II-4.3.1 Graduations should be clearly and permanently marked. The numerals should be distinct and placed in such a way that there is no possibility of any ambiguity.

II-4.3.2 Gauge plates should be manufactured in suitable lengths with the face of the scale not less than 50 mm in width.

II-4.3.3 The markings of the subdivisions should have a precision of  $\pm 0.5$  mm, and the cumulative error in length should not exceed 0.1 per cent or 0.5 mm, whichever is greater.

### II-4.4 Installation and use

#### II-4.4.1 General

- (a) The gauge should preferably be placed near the bank so that a direct reading of water level may be made.
- (b) The gauge should be located as close as possible to the measuring section without affecting the flow conditions at this point.
- (c) It should be readily and conveniently accessible so that the observer may make readings as near as possible to eye level.

#### II-4.4.2 Vertical gauges

The gauge board or backing plate should be securely fastened to the surface of a wall or to piles having a vertical face parallel to the direction of flow.

#### II-4.4.3 Stepped gauges

Where the range of water levels exceeds the capacity of a single vertical gauge, additional sections may be installed on the line of the cross-section normal to the direction of flow.

- (a) Stepped gauges should be installed at such intervals as to ensure the measurement of water level at all stages.
- (b) The scales on the series of stepped gauges should have an adequate overlap.

#### II-4.4.4 Inclined gauges

An inclined gauge should be installed in such a manner as to follow closely the contour of the river bank and should be calibrated in situ by precise levelling from the station benchmark.

## II-5 Needle gauges

A needle water-level gauge consists of a point and some means of determining its exact vertical position relative to a datum. The two types of needle gauge are:

- (a) The point gauge, whose tip approaches the free surface from above;
- (b) The hook gauge, which is hook-shaped, and whose tip is immersed and approaches the free surface from below.

The vertical position may be determined by a graduated scale, a tape with some vernier arrangement, or a digital indicator.

### II-5.1 Functional requirements

- (a) A needle gauge installation should permit measurement of stage to be made at all levels from below the lowest to above the highest level anticipated.
- (b) There should be good illumination of the place where the tip meets the free liquid surface.
- (c) The tip should be tapered to a point having an included angle of approximately 60° and the point should be rounded to a radius of approximately 0.25 mm.

### II-5.2 Material

A needle gauge and auxiliary parts should be made throughout of durable corrosion-resistant materials.

### II-5.3 Graduation

The graduation of a hook or point gauge should be in millimetres and should be clearly and accurately marked.

### II-5.4 Installation and use

- (a) A needle should be mounted over an open water surface at the edge of a stream if conditions permit. If this is not practicable because of turbulence, wind effect or inaccessibility, a stilling bay or stilling well should be installed.
- (b) The location of the needle gauge should be as close as possible to the measuring section.
- (c) Where more than one datum plate or bracket is provided at different levels, or where a stepped gauge is used, all should lie on a single cross-section normal to the direction of flow in the stream. If this is not practicable and it is necessary to stagger the points, all should lie within a distance of one metre on either side of the cross-section.
- (d) Datum plates and brackets should be mounted on a secure foundation which extends below the frost line.
- (e) The elevation of the datum plates, with reference to which the level of the free surface is determined, should be established with great care. The tolerance

on the transfer of level from the station benchmark to each datum plate should not exceed  $\pm 1.0$  mm.

## II-6 Float gauges

NOTE: The float gauge is used to measure stage usually inside a stilling well. A typical float gauge consists of a float operating in a stilling well, a graduated steel tape, a counterweight, a pulley and a pointer.

### II-6.1 Functional requirements

- (a) A float gauge installation should permit measurement of stage to be made at all levels from the lowest to the highest level anticipated.
- (b) The float should be made of durable corrosion-resistant and antifouling material. It should be leakproof and function in a truly vertical direction.
- (c) The float should float properly and the tape or wire should be free of twists or kinks.
- (d) A means should be provided for readily checking the float gauge readings with the actual stream stage.

### II-6.2 Graduation

The graduations of a float gauge should be in millimetres and should be clearly and accurately marked.

## II-7 Wire-weight gauges

NOTE: A typical wire-weight gauge consists of a drum wound with a single layer of cable, a bronze weight attached to the end of the cable, a graduated disc and a counter, all housed within a protective housing. The wire-weight gauge is used as an outside reference gauge where other outside gauges are difficult to maintain. The wire-weight gauge is normally mounted where there is a bridge or other structure over the water.

### II-7.1 Functional requirements

A wire-weight gauge should permit measurement of stage throughout the range of levels anticipated.

### II-7.2 Material

A wire-weight gauge should be made throughout of durable corrosion-resistant materials.

### II-7.3 Graduation

The graduations of a wire-weight gauge should be in millimetres.

### II-7.4 Installation and use

- (a) The gauge should not be installed in a location where the water surface is disturbed by turbulence, wind effects or afflux.
- (b) The elevation of a wire-weight gauge should be verified frequently to ensure reliability of stage observations.

## II-8 Pressure gauges

NOTE: Pressure gauges are frequently used at sites where it would be too expensive to install stilling wells. A widely used method of measuring water level is to measure the height of a column of water with respect to some datum plane. This can be accomplished indirectly by sensing the water pressure at a fixed point below the water surface and then utilizing the hydrostatic principle that the pressure of a liquid is proportional to the depth. The most successful and widely used method of transmitting the pressure is the gas-purge technique.

### II-8.1 Gas-purge (bubbler) technique

- (a) An adequate supply of gas or compressed air should be provided. The supply should have a delivery pressure in excess of the range to be measured.
- (b) A pressure-reducing valve should be provided so that a pressure safely in excess of that of the maximum range can be set. A flow control valve and some form of visual flow rate indicator should be installed so that the discharge of gas supplied to the system can be properly adjusted. The pressure should be set to prevent water from entering the tube, even under the most rapid rates of change expected.
- (c) Incorrect readings due to the friction of the gas moving through the tube should be minimized.
- (d) The tubing should be installed with a continuous downslope to the orifice.

### II-8.2 Water density compensation

Since the density of the water which the sensor is to measure will vary with temperature and also with chemical and silt content, either automatic or manual means of compensating for these changes should be provided.

### II-8.3 Changes in gas weight

If the gas technique is used to transmit pressure, provisions should be made for compensating for changes in the density of the gas with temperature and pressure.

### II-8.4 Range

The range of the instrument should be adequate to accommodate the anticipated range in water level.

### II-8.5 Response

The response of the instrument should be sufficiently rapid to follow any expected rate of change in water level.

## II-9 Recording devices

### II-9.1 Mechanical recorders

#### II-9.1.1 Driving torque

NOTE: In the recording devices, the angular movement of the input shaft is transformed by mechanical linkage into movement of the stylus of an analogue recorder or into the coding mechanism of a digital recorder. If the friction is

high, i.e. the driving torque required to position the recording element is high, then there is an appreciable time lag following a water-level change.

- (a) The driving torque should be sufficient to overcome the friction generated by mechanical linkages.
- (b) The friction should be as low as feasible and should not exceed 7 mN.m.

#### II-9.1.2 Hysteresis (lost motion)

Hysteresis should be kept to a minimum and should not exceed 3 mm.

NOTE: If the input shaft is rotated in one direction until the stylus follows and then the direction of rotation reversed, the total hysteresis is the amount of motion required to cause the stylus to follow in the reversed direction.

#### II-9.1.3 Timing mechanism

- (a) The clock mechanism which rotates the chart plate should be of high quality, sturdy and reliable and should be protected from dirt, corrosion and insects by its housing.
- (b) The uncertainty in the time measurement or the clock-work should not exceed  $\pm 30$  s/d average over a period of at least 30 days.
- (c) A movement adjustment should be provided to permit regulation within the accuracy requirements set forth in (b).

#### II-9.1.4 Paper (chart or tape)

The paper used should remain stable within relatively close tolerance throughout the range of temperature and humidity conditions expected.

#### II-9.1.5 Stylus

If a pen is used, the pen and ink should be such that an easily readable trace is produced without blotting. If a pencil is used, it should be of proper hardness to produce a readable trace.

#### II-9.1.6 Errors

The sources of errors when using a recording device are as follows:

- (a) Friction in the driving mechanism;
- (b) Hysteresis in the driving mechanism;
- (c) Line shift, caused by change in depth of flotation of the float when the stage changes rapidly and with it the weight of the float line changes;
- (d) Expansion and contraction of paper;
- (e) Ambiguity, if the stage is between digits (in digital recorders).

In digital recorders, if the stage is between digits, the recorder should be forced to the nearest digit before the tape is punched in order to prevent ambiguity.

**II-9.1.7 Environmental requirements**

The recorder should operate satisfactorily over the prevailing ranges of ambient temperature and relative humidity.

**II-9.1.8 Material**

All parts of the recorder should be manufactured of materials which will resist corrosion under conditions of field usage.

**II-9.1.9 Housing**

The recorder should be housed in a drip-proof, dust-proof, weather-resistant case. The case should contain a window so that visual inspection of the recorder can be made without opening the case.

**II-9.1.10 Levelling of the input shaft**

Means of horizontal levelling of the input shaft should be provided.

**II-9.1.11 Operational manual**

A general operational manual should be provided with such descriptions and diagrams as necessary for proper operation and maintenance of the recorder.

**II-9.2 Pressure-actuated recorders****II-9.2.1 Pressure range**

- (a) The pressure range of the recorder should be selected to encompass the expected total range of the pressure of the water. Allowance should be made for any extreme condition to avoid damage to the pressure-sensing element.
- (b) The mechanical and pressure-sensing elements should be of high quality, both in material and workmanship to minimize hysteresis.
- (c) A means should be incorporated in the recorder for adjusting for altitude.

**II-9.2.2 Timing mechanism**

As in II-9.1.3 above.

**II-9.2.3 Paper (chart or tape)**

As in II-9.1.4 above.

**II-9.2.4 Stylus**

As in II-9.1.5 above.

**II-9.2.5 Environmental requirements**

The recorder should operate satisfactorily over the prevailing ranges of ambient temperature, relative humidity and atmospheric pressure.

**II-9.2.6 Material**

As in II-9.1.8 above.

**II-9.2.7 Housing**

As in II-9.1.9 above.

**II-9.2.8 Operational manual**

As in II-9.1.11 above.

**II-9.3 Electronic recorders****II-9.3.1 Accuracy**

The uncertainty in the records of the electronic recorder should not exceed 0.5 per cent of its full scale reading.

**II-9.3.2 Readability**

The overall movement of the operating mechanism (stylus) should be adequate to allow resolution of the smallest increment. The width of the chart paper should be at least equal to the stylus movement.

**II-9.3.3 Stability**

A recorder used for the recording of water level should be stable within  $\pm 2$  readability divisions over a 30-day period.

NOTE: The stability of the recorder is its ability to maintain the same reading within a given tolerance for the same input signal.

**II-9.3.4 Timing mechanism**

As in II-9.1.3 above.

**II-9.3.5 Paper**

Paper of only the best quality and with an accurate scale printing should be used.

**II-9.3.6 Stylus**

As in II-9.1.5 above.

**II-9.3.7 Environmental requirements**

As in II-9.1.7 above.

**II-9.3.8 Material**

The recorder should be constructed of materials and housed in a manner as to function satisfactorily under conditions of field usage for prolonged periods of time.

**II-9.3.9 Housing**

As in II-9.1.9 above.

**II-9.3.10 Operational manual**

As in II-9.1.11 above.



## III – DIRECT DEPTH SOUNDING AND SUSPENSION EQUIPMENT

(See [D.1.2.] 3.1.3)

### III-1 Scope and field of application

NOTES:

- (a) The material in this section of the annex is based on ISO 3454 (1983) entitled "Liquid flow measurement in open channels — Direct depth sounding and suspension equipment".
- (b) Detailed guidance on sounding and suspension equipment is given in the *Guide to Hydrological Practices* (WMO-No. 168) and in the *Manual on Stream Gauging* (WMO-No. 519).

This section specifies the functional requirements of the equipment in use in the measurement of liquid flow in open channels, for:

- (a) Sounding the depth of water;
- (b) Suspending the measuring equipment (current meter or sediment sampler) in order to conform to the requirements of Technical Regulation [D.1.2.] 3.1 and to meet the discharge measurement accuracy requirements indicated in Technical Regulation [D.1.2.] 3.6.

### III-2 Sounding equipment

NOTE: The object of sounding is to obtain the depth from water surface to channel bed. For this purpose, either a rod or a sounding line is used, depending on velocity and depth of flow.

#### III-2.1 Sounding rod

NOTE: A sounding rod is rigid in construction. It may be either hand-held and hand-operated or provided with a support and mechanically operated.

III-2.1.1 The hand-held sounding rod may be used for measurement of depth up to 3 metres in velocities up to 2 m/s.

NOTE: A supported mechanically operated rod is generally suitable for depths up to 6 metres and velocities up to 2 m/s.

III-2.1.2 For small depths and velocities (up to 1 metre and 1 m/s respectively) a wading rod should be used.

III-2.1.3 During measurements, the rod should be held in a vertical position.

### III-2.2 Sounding line

III-2.2.1 The sounding line should be used in situations where depth and velocities preclude the use of a sounding rod.

III-2.2.2 An appropriate weight should be attached to the sounding line to keep it vertical.

#### III-2.3 Sounding weight

Sounding weights should be streamlined to offer minimum resistance to flowing water.

NOTE: An estimate of the sounding weight mass required to suit certain depth and velocity can be found using the following formula:

$$m = 5\bar{v}d$$

where:

- $m$  is the mass of the sounding weight, in kg;
- $\bar{v}$  is the mean velocity of flow, in m/s;
- $d$  is the depth of water, in m.

### III-3 Suspension equipment

#### III-3.1 Suspension equipment

It should:

- (a) Be such that the suspended measuring or sampling device may be placed at a selected depth and position, avoiding undue disturbance irrespective of the depth and velocity;
- (b) Maintain the measuring or sampling device at the selected depth and position in a stable condition during the period of observation.

#### III-3.2 Rod suspension equipment

NOTE: Rod suspension equipment has the merit that a measuring or sampling device can be placed at the point of measurement without any appreciable deflection from the vertical.

##### III-3.2.1 Hand-operated rod suspension equipment

Wading rods should be used in shallow streams suitable for wading and may be used in water of depths up to 3 metres and velocities up to 2 m/s.

### III-3.2.2 **Mechanically operated rod suspension equipment**

NOTE: Although this equipment allows accurate positioning of the measuring or sampling device at the required depth and position it is heavier and requires careful installation and skilled handling.

Mechanically operated suspension equipment may be employed where the use of a hand-held rod becomes impracticable, but generally should not be used in depths exceeding 6 metres and velocities exceeding 2 m/s.

### III-3.3 **Cable suspension equipment**

III-3.3.1 Cable suspension equipment should be used in situations where depths and velocities preclude the use of rod suspension.

NOTE: Two types of cable suspension equipment are in common usage:

- (a) Hand-line suspension, which can be used with weights up to 15 kg;
- (b) Winding reel suspension supported on a bridge, cable car, boat or ice cover which should be used if the sounding weight exceeds 15 kg.

III-3.3.2 When the flow deflects the suspension line downstream so that the angle of the line from the vertical exceeds four degrees, an unacceptable error in indicated depth is introduced and two separate corrections should be applied to the indicated depth:

- (a) An "air-line" correction for that part of the cable which is between the point of suspension and the water surface;
- (b) A "wet-line" correction for that part of the cable which is in the water.

NOTE: Correction tables are given in the *Manual on Stream Gauging* (WMO-No. 519), Volume I — Fieldwork, pages 141 and 143.

## III-4 **Specific requirements**

### III-4.1 **Rods for sounding and suspension**

#### III-4.1.1 **Hand-held sounding and suspension rod**

This equipment should satisfy the following requirements:

- (a) Its mass should be as small as possible;
- (b) It should be straight and have sufficient strength to withstand the force due to flowing water without significant deflection or vibration — it may be sectional to allow it to be dismantled;
- (c) Construction should be of corrosion-resistant material;
- (d) It should not cause significant heading up of water due to its own obstruction;
- (e) The interval between graduations should permit observation to within 10 mm; graduation increments of 0.1 m, 0.5 m and 1 m should be clearly identified;

- (f) It should incorporate a foot plate to prevent penetration into the bed of the channel;
- (g) It should incorporate a movable mounting for equipment and a means of conveying an electric signal.

#### III-4.1.2 **Mechanically operated sounding and suspension rod**

In addition to the requirements in III-4.1.1 (a) to (g) mechanically operated rod equipment (see III-3.2 above) should have the following features:

- (a) A locking arrangement such as pawl-and-ratchet to hold the sounding or suspension rod in the desired position;
- (b) A mechanical arrangement to raise and lower the sounding or suspension rod easily;
- (c) An arrangement for safely securing it to the gauging platform or structure;
- (d) Sufficient counterbalancing to ensure stability.

### III-4.2 **Cable sounding and suspension equipment**

#### III-4.2.1 **Sounding and suspension cable**

The cable used with sounding and suspension equipment should:

- (a) Be corrosion resistant, preformed and reverse-laid to inhibit spinning;
- (b) Be equipped with a suitable attachment for suspending the measuring equipment and weights;
- (c) Incorporate insulated conductors suitable for the transmission of signals from the instrument;
- (d) Be constructed to that in normal use it will not sustain any permanent bends or twists, which would affect its utility and length;
- (e) Have sufficient strength to support the current meter and sounding weight safely. Its elongation under load should not exceed 0.5 per cent.

NOTE: A breaking load of not less than five times the maximum sounding weight provides a suitable safety margin to allow for the loading effects of drag and the live load. Where the cable is to be used as a hand line the portion of the cable to be handled should be of a suitable material and dimension (e.g. 10-mm diameter, with PVC or rubber cover) to avoid discomfort or injury to the operator. The wet-line portion should have a diameter as small as possible (consistent with the conditions stated in (a) to (e) in order to minimize drag).

#### III-4.2.2 **Winding reels**

Winding reels used to dispense and measure the suspension cable should satisfy the following requirements:

- (a) The radii of drums, pulleys and cable guides should not be less than the minimum cable bending radius recommended by the manufacturer;

- (b) There should be a device to measure the amount of cable paid out. It may be driven by the drum when the cable can be accommodated in a single layer, otherwise driven directly by the cable;
- (c) There should be an arrangement to ensure that the cable is wound evenly on to the drum; the end of the cable shall be securely fastened to the drum;
- (d) There should be a locking arrangement to hold the drum at any desired position;
- (e) There should be provision for an electrical connection between the recording equipment and the suspended instrument;
- (f) The design of the reel should be such that hand operation will be easy, the drum may be provided with a power drive unit for raising and lowering the measuring equipment and attached weight; the method of attachment to the supporting device should be simple and safe. The supporting device may be a cable car, bridge board, ice frame, crane, boat boom, etc.

#### III-4.2.3 **Supports and mounting structures for winding reels**

Supports and mounting structures to be used on or attached to bridges, cable cars, boats, or ice:

- (a) Should be of adequate strength to support the winding reel together with the measuring or sampling equipment and any attached weight;
- (b) Should enable the measuring or sampling equipment to be lowered or raised in a vertical plane

giving adequate clearance from the support structure;

- (c) Should incorporate a protractor to measure the deviation of the cable from the vertical;
- (d) Should incorporate adequate counterbalancing to ensure its stability at all times;
- (e) May have provision for attaching a power-drive unit;
- (f) Should be mobile in order that it can be easily transported and to this end it may be collapsible.

#### III-4.2.4 **Sounding weights**

Sounding weights should be constructed of a dense material to minimize volume, streamlined to minimize drag and fitted with fins to provide directional stability. The location of the weight with respect to the measuring instrument should be such as to minimize its effect on the operating characteristics of the instrument. The anchorage point for the attachment of the weight to the suspension cable should be made as small as possible or incorporated in the body of the weight. Attaching two or more weights to the sounding or suspension cable is not recommended.

NOTE: In addition, the weight may:

- (a) Be equipped with a device to detect and signal contact with the bed;
- (b) Have other hydrometric equipment attached directly to it;
- (c) Be part of an assembly having an overhanging support for securing hydrometric equipment.



## IV – ROTATING ELEMENT TYPE CURRENT METERS

(See [D.1.2.] 3.1.4)

### IV-1 Scope and field of application

NOTES:

- (a) The material in this section of the annex is based on ISO 2537 (1988) entitled "Liquid flow measurement in open channels — Rotating element current meters".
- (b) Detailed guidance on current meters is given in the *Guide to Hydrological Practices* (WMO-No. 168) and in the *Manual on Stream Gauging* (WMO-No. 519).

This section specifies the operational requirements, construction, calibration and maintenance of rotating element current meters in order to conform to the requirements of Technical Regulation [D.1.2.] 3.1.4.

### IV-2 Operational requirements

NOTE: Current meters of conventional construction are intended to operate in a horizontal or near horizontal position. Current meters designed to operate in other positions are not covered by this section.

IV-2.1 The equipment should maintain alignment with the flow in such a way that the rotating element responds to flow movement as intended. If a pivoted suspension is incorporated within the current meter, it should permit freedom in the vertical plane to ensure correct alignment with the liquid flow.

IV-2.2 The current meter should offer minimum resistance to the force of the current.

IV-2.3 The rotating element of the current meter should be such that, when driven by the fluid, it rotates at an angular velocity which has a known relation to the velocity of the flow within the calibrated velocity range stated by the manufacturer or rating laboratory.

IV-2.4 The meter should respond rapidly and consistently to changes in velocity; the manufacturer should state the expected response rates.

IV-2.5 Unless indicated otherwise, the current meter should be suitable for use in silty and/or saline waters.

### IV-3 Constructional features

IV-3.1 The propellers should be made from a material which will not allow them to be easily distorted or bent.

IV-3.2 The resisting torque of the bearings should be as small as possible and should be constant during use. Bearings should be lubricated as stated by the manufacturer. Provision should be made to keep silt and water from the bearings except as required for water-lubricated bearings.

IV-3.3 The revolutions of the rotor should, by means of mechanical contacts or by means of magnetic, optical or other devices, give a clear and positive signal at all velocities within the effective range of the meter. If electrical connections are used, they should be appropriately waterproofed.

IV-3.4 Manufacturers should stipulate the maximum conductivity of water in which the meter can be used.

IV-3.5 For the measurement of low velocities, it should be possible to choose the frequency of signals transmitted by the counting mechanism in such a way as to reduce to a minimum the errors entailed in measurements of normal duration.

IV-3.6 For the measurement of high velocities, if the frequency of the signals is such that they can no longer be counted or indicated properly, a device that will detect all input signals at these high velocities should be provided.

IV-3.7 Spare parts should be fully interchangeable so as to have uniform functional characteristics and should cause less than 2 per cent divergence from the calibration.

IV-3.8 Current meters should be constructed of corrosion-resistant materials throughout or of materials that are effectively protected against corrosion encountered in natural waters. The meter should be of sufficiently rugged construction to maintain calibration under conditions normally encountered.

### IV-4 Calibration

IV-4.1 All calibrations should conform to the requirements set out in section I of this annex.

IV-4.2 When current meters are calibrated, either individually or by groups, a calibration document as specified in section I, I-5.4 of this annex should be furnished with each meter.

IV-4.3 Group ratings should be based on the calibration of a group of current meters of uniform manufacture. The sample calibrated should be adequate in number and

should comprise, if possible, both new current meters and well-maintained used current meters.

IV-4.4 If group ratings are used, the calibration of meters should be periodically checked to ensure that they continue to operate within the expected tolerances.

IV-4.5 Individually calibrated current meters should be recalibrated on a routine basis at yearly intervals or after 300 hours of use, whichever is the shorter.

IV-4.6 Apart from the regulations above, a current meter should be recalibrated whenever its performance is suspect.

IV-4.7 For the reliability of the calibration, the rating laboratory should state tolerance limits at the 95 per cent confidence level at velocities of 0.15, 0.25 and 0.50 m/s and above.

IV-4.8 As a check for goodness of fit of the calibration curve, the manufacturer or rating laboratories should state the standard error of the data for the lower and upper limits of calibration, and for at least two intermediate points. The standard error should be stated as a percentage of the mean velocity class and should be related to the 95 per cent confidence limits.

#### IV-5 **Maintenance**

NOTE: In general, under conditions of normal operation, the user should follow recommended check procedures before and after each discharge measurement, as laid down in the manufacturer's operations and servicing manual.

IV-5.1 The meter should be examined, before and after each discharge measurement, for worn or damaged bearings, proper shaft alignment, correct operation of contact points and deformation of the yoke or cup-wheel in the case of cup-type meters, or of the propeller in the case of propeller-type meters.

IV-5.2 For inspection, it should be possible to dismantle and reassemble the current-meter assembly in the field,

without specialized workshop facilities and by personnel without specialist training. The tools which are required to carry out this operation should be supplied as standard accessories.

IV-5.3 Before use, the meter should be tested for correct operation by the signal test. By turning the rotor slowly, the number of rotations should be compared with the number of pulses received. For current meters with a generator, it should be checked that the output varies with rotor speed.

IV-5.4 The condition of the current meter should be determined by the spin test, both before and after being used for a discharge measurement.

NOTE: The spin test is performed as follows: Place the meter in the normal operating position, with the rotor protected from air current; spin the rotor by hand; as it nears its stopping point, observe its motion carefully to see whether the stop is abrupt or gradual. If the stop is abrupt, the cause should be found and corrected before the meter is used.

IV-5.5 The manufacturer should specify the duration of spin which should be expected for any particular type of current meter.

IV-5.6 The duration of the spin should be timed and noted, and compared with the minimum duration specified for the current meter.

IV-5.7 After each discharge measurement, or more frequently for extended measurements, all bearing surfaces should be thoroughly cleaned and, where appropriate, lubricated. The oil used should have the same specifications as recommended by the manufacturer.

IV-5.8 A suitable protective case for transport and storage should be provided for the current meter, the spare parts and the maintenance tools.

IV-5.9 A comprehensive operational and servicing manual should be supplied with each instrument. It should present full instructions and be illustrated where necessary.

## V – PRECALIBRATED WEIRS FOR THE DETERMINATION OF DISCHARGE

(See [D.1.2.] 3 1.5)

### V-1 Scope and field of application

NOTES:

- (a) The material in this section of the annex is based on ISO 1438-1 (1998) entitled "Water flow measurement in open channels using weirs and Venturi flumes — Part 1: Thin-plate weirs", ISO 3846 (1989) entitled "Liquid flow measurement in open channels by weirs and flumes — Rectangular broad-crested weirs", ISO 4360 (1984) entitled "Liquid flow measurement in open channels by weirs and flumes — Triangular-profile weirs", ISO 4374 (1990) entitled "Liquid flow measurement in open channels — Round-nose horizontal broad-crested weirs" and ISO 4377 (2002) entitled "Hydrometric determinations — Flow measurement in open channels using structures — Flat-V weirs".
- (b) Details of relevant discharge equations are given in the above ISO Standards. Further guidance on the determination of discharge is given in the *Guide to Hydrological Practices* (WMO-No. 168) and the *Manual on Stream Gauging* (WMO-No. 519).

This section specifies the functional requirements for the measurement of discharge using:

- (a) Thin-plate weirs;
- (b) Rectangular broad-crested weirs;
- (c) Triangular-profile weirs;
- (d) Round-nose horizontal-crest weirs;
- (e) Flat-V weirs;

to conform with the requirements of Technical Regulation [D.1.2.] 3.1.5.

### V-2 Selection of site

V-2.1 The weir should be located in a straight reach of channel and local obstructions, changes in roughness, or unevenness of the bed should be avoided.

V-2.2 A preliminary survey should be made of the proposed site as set out in section VI, VI-4.15.

V-2.3 The site selected should comply, in so far possible, with the requirements specified in VI-3.2 in general, and VI-4.16 in particular, of section VI.

### V-3 Installation conditions

The complete measuring installation should consist of an approach channel, a measuring structure and a downstream channel.

#### V-3.1 Approach channel

V-3.1.1 The flow in the approach channel should be smooth and free from disturbances and should have as even as possible a velocity distribution over the cross-section. Large rocks and boulders should be cleared from the bed of the approach section. A standing wave should not occur upstream of the structure within a distance of 30 times the maximum head.

V-3.1.2 The cross-section should be uniform and the approach channel should be straight for a length equal to at least five times the water surface width at maximum flow.

V-3.1.3 Where the entry to the approach channel is through a bend, discharged into the channel through a conduit or smaller cross-section, or at an angle, the straight approach channel should be long enough to achieve an even velocity distribution.

V-3.1.4 Where baffles are used in an artificial channel, free of debris or matter carried in suspension, there should be no baffle nearer to the point of measurement than 10 times the maximum head to be measured.

#### V-3.2 Measuring structure

V-3.2.1 The weir structure should be rigid and watertight, capable of withstanding floodflow conditions, and should be at right angles to the direction of flow.

V-3.2.2 In the case of a thin-plate weir, the wall on which it is built should be free from projections, and its upstream face should not protrude beyond the face of the weir. On the downstream side, the structure should be such that it does not interfere with the aeration of the nappe.

V-3.2.3 The ground on which the structure is to be founded should be impermeable or sealed by grouting, piling or other means.

**V-3.3 Downstream of the structure**

For weirs designed for free-flow conditions, any accumulation of debris in the channel downstream of the structure, which might raise the water level sufficiently to drown the structure, should be removed.

**V-4 Measurement of head**

The head upstream of the weir should be measured by an appropriate water-level measuring device as described in section II of this annex.

**V-5 Maintenance**

V-5.1 The approach channel should be kept clean and free from silt and vegetation for at least the distance specified in V-3.1.2 above.

V-5.2 The float well and the entry from the approach channel should be kept clean and free from deposits.

V-5.3 The weir structure should be kept clean from clinging debris.

## VI – ESTABLISHMENT AND OPERATION OF A HYDROMETRIC STATION

(See [D.1.2.] 3.3.1)

### VI-1 Scope and field of application

NOTES:

- (a) The material in this section of the annex is based on ISO 1100-1 (1996) entitled “Measurement of liquid flow in open channels — Part I: Establishment and operation of a gauging station” and on ISO 748 (1997) entitled “Measurement of liquid flow in open channels — Velocity-area methods”.
- (b) Detailed guidance on establishment and operation of a hydrometric station is given in the *Guide to Hydrological Practices* (WMO-No. 168) and in the *Manual on Stream Gauging* (WMO-No. 519).

This section specifies the requirements in the establishment and operation of a hydrometric station for the measurement of stage or discharge, or both, in order to conform to the requirements of Technical Regulation [D.1.2.] 3.3 and to meet the requirements for accuracy of measurement indicated in Technical Regulations [D.1.2.] 3.5 and [D.1.2.] 3.6.

### VI-2 Water-level (stage) gauging station

#### VI-2.1 Preliminary survey

A preliminary survey should be made of the physical and hydraulic features of the proposed site to ensure that it conforms to the requirements necessary for the measurement of water level as specified in section II — Water-level measuring devices.

#### VI-2.2 Selection of site

VI-2.2.1 The site selected for stage observation should be governed by the purpose for which the records are collected, the accessibility of the site and the availability of an observer if the gauge is non-recording.

VI-2.2.2 Gauges on large bodies of water should be located so as to reduce the fetch of strong winds which may cause misleading data.

VI-2.2.3 Hydraulic conditions should be given importance in site selection on channels, particularly where water levels are used to compute discharge records.

### VI-2.3 Design and construction

A water-level gauging station should consist essentially of a reference gauge or gauges. When a continuous record of stage is required a water-level recorder should be installed in addition to the reference gauge.

NOTE: Specifications of various types of water-level measuring devices, their installation and use are given in section II of this annex.

### VI-3 Station for the measurement of discharge; individual measurements

NOTE: The methods which follow are most suitable for a single measurement, a limited number of measurements or infrequent measurements of discharge, but where no continuous record of discharge is desired.

#### VI-3.1 Velocity-area methods and principle of method

The velocity and area of cross-section of flow in an open channel are measured and from these is obtained the discharge.

#### VI-3.2 Selection of site

VI-3.2.1 Approximate measurements of widths, depths and velocities should be made in a preliminary survey to investigate the suitability of a site. These measurements should be used as a guide to ensure that both longitudinal and transverse bed profiles and the velocity distribution are acceptable for the purpose of discharge measurement.

VI-3.2.2 At the site selected it should be possible to measure the whole range of discharges and all types of flow which may be encountered or which it is required to measure.

VI-3.2.3 The site selected should comply, as far as possible, with the following requirements:

- (a) The channel at the measuring site should be straight and of uniform cross-section and slope. If the length of the straight channel is restricted, the straight length upstream of the measuring section should be twice that downstream;

- (b) The depth of water in the selected reach should be sufficient to provide for the effective immersion of either the current meter or floats, whichever are to be used;
- (c) The measuring site should be clear and unobstructed by trees or other obstacles.

VI-3.2.4 In addition to the requirements specified in VI-3.2.3 the following points should be taken into consideration when selecting the measuring site:

- (a) Degree of accessibility;
- (b) The bed of the reach should not be subject to changes during the period of measurement;
- (c) All discharges should be contained within a defined channel or channels having substantially stable and well-defined boundaries;
- (d) The site should be remote from any bend or natural or artificial obstruction;
- (e) Sites where weed growth is prevalent should be avoided, if possible;
- (f) Sites at which vortices, backward flow, or dead-water zones tend to develop should be avoided;
- (g) Sites with converging, and more so with diverging, flow over an oblique measuring section should be avoided;
- (h) The orientation of the reach should be such that the direction of flow is as closely as possible normal to that of the prevailing wind;
- (i) Sites which are subject to variable backwater should be avoided if at all possible;
- (j) Flood plains, if they cannot be avoided, should be of minimum width, as smooth as possible, without a distinct channel, and clear of bushes and trees;
- (k) A measuring site in the vicinity of a bridge should be preferably upstream of the bridge. However, where accumulation of ice, logs or debris is liable to occur, the measuring site should be downstream of the bridge;
- (l) For a stream subject to formation of ice cover, the following conditions should be adhered to:
  - (i) The ice should be strong enough to bear the weight of persons and their equipment for large proportion of the time that the stream is frozen. Therefore, safe methods shall be used to determine the strength of the ice while it is forming, and particularly while it is melting;
  - (ii) Measuring sites should be upstream of reaches of open water to minimize presence of slush or frazil ice;
  - (iii) The measuring site should be chosen so that the presence of many layers of ice is avoided. Ice layers may occur at sites subject to many water-level fluctuations or ones which freeze to the bottom;

NOTE: Where these requirements cannot be met at an otherwise good gauging site, a different site may be used for winter measurements provided that there is negligible local inflow

between the two sites. In some cases, it may be necessary to use more than one site for winter measurements. These alternate winter measurement sites should be evaluated during the open-water season to assess their suitability with respect to the conditions mentioned above.

- (m) If, after the site has been selected, unacceptable changes occur in the channel conditions, another site should be selected.

VI-3.2.5 The topographical survey of the selected site should include a plan of the site and details of the channel, bed and flow characteristics of the measuring section.

### VI-3.3 Design and construction

VI-3.3.1 The site, after selection, should be provided with means for demarcation of the cross-section and for determination of the stage.

VI-3.3.2 The position of each cross-section should be defined on the banks of the river by clearly visible and readily identifiable permanent markers, and a station benchmark should be established.

NOTE: Where a site is subject to considerable snow cover the section line markers may be referenced to other objects such as rock cairns.

VI-3.3.3 A reference gauge should be installed for checking changes in the water level which may occur during a gauging.

VI-3.3.4 The datum of the gauge for measurement of stage should be related by precise levelling to a standard datum.

VI-3.3.5 An auxiliary gauge on the opposite bank should be installed where there is likelihood of a difference in the level of the water surface between the two banks.

NOTE: This is particularly important in the case of very wide rivers.

VI-3.3.6 Trees obstructing the clear view of the measuring section or measuring reach should be trimmed or removed.

VI-3.3.7 A suitable access to the site should be constructed, where possible, to provide safe passage at all stages of flow and in all weather.

VI-3.3.8 All key points at the site should be permanently marked on the ground by markers sunk to such a depth below the surface as will secure them against subsidence.

#### VI-3.3.9 Reference gauge

The reference gauge should conform to the specifications set out in section II of this annex.

#### VI-3.3.10 Station benchmark

A station benchmark should be established to conform to the specifications set out in section II of this annex.

#### VI-3.3.11 Stilling well

The stilling well should conform to the specifications set out in section II of this annex.

### VI-3.3.12 **Water-level recorder**

The water-level recorder should conform to the specifications set out in section II of this annex.

### VI-3.3.13 **Sounding and suspension equipment**

Suspension equipment of the current meter should conform to the specifications set out in section II of this annex.

### VI-3.4 **Definitive survey**

VI-3.4.1 After the gauging station has been constructed, a definitive survey should be made.

VI-3.4.2 For discharge measuring stations, a standard profile of the measuring cross-section should be drawn, indicating the position of the cross-section markers. The profile should be checked frequently and revised if necessary. A copy of the standard profile (most recent revision) should be kept in the instrument house at all times.

VI-3.4.3 For float-gauging stations, a standard plan should be prepared on which the lines of the selected float runs and the release points for floats should be indicated. A copy of this plan should be kept in the instrument house at all times.

VI-3.4.4 The definitive survey, repeated as required at not less than annual intervals, should include the accurate determination of the elevations and the relative positions of all the station installations and any other key point or significant feature of the site.

### VI-3.5 **Measurement of cross-sectional area**

#### VI-3.5.1 **Measurement of width**

VI-3.5.1.1 The width of the channel and the widths of the individual segments should be measured from or to a fixed reference point which should be in the same vertical plane as the cross-section.

VI-3.5.1.2 Where the width of the channel permits, or when the surface is covered by ice, the width should be measured by direct means, for example by a steel tape or suitably marked wire, care being taken to apply the necessary corrections. The intervals between the verticals, i.e. the widths of the segments, should be similarly measured.

NOTE: The corrections which may be necessary are:

- (a) Correction for sag;
- (b) Correction for pull;
- (c) Correction for slope;
- (d) Correction for temperature.

VI-3.5.1.3 Where the channel is too wide for the above methods of measurement, the distance should be determined by optical or electrical distance meters, or by one of the common surveying methods.

NOTE: The common surveying methods are:

- (a) Angular method;
- (b) Linear method;
- (c) Pivot-point method.

VI-3.5.1.4 The uncertainty in the measurement of width should not exceed 0.5 per cent of the true value.

VI-3.5.1.5 The distance between successive cross-sections used for the measurement of velocity by floats should be determined by methods similar to those described above and to a similar degree of accuracy.

#### VI-3.5.2 **Measurement of depth**

VI-3.5.2.1 Measurement of depth should be made at intervals close enough to define the cross-sectional profile accurately. In general, the intervals should not be greater than 1/15 of the total width in the case of regular bed profiles and 1/20 in the case of irregular bed profiles.

NOTE: For small channels with a regular bed profile, the number of intervals may be reduced.

VI-3.5.2.2 The depth should be measured employing either sounding rods or sounding lines or other suitable devices as specified in section III of this annex.

NOTE: Where the channel is of sufficient depth, an echo sounder may be used. If the velocity is high, it is preferable to use an echo sounder or other device which will not require large corrections.

VI-3.5.2.3 When a sounding rod or sounding line is used, at least two readings should be taken at each point and the mean value adopted for calculations, unless the difference between the two values is more than 5 per cent in which case two further readings should be taken.

VI-3.5.2.4 When an echo sounder is used, the average of several readings should always be taken at each point and frequent calibrations of the instrument should be made.

VI-3.5.2.5 When depths are determined by soundings referred to the water surface, frequent readings of the water level should be made on the reference gauge to ensure that all measurements may be corrected to the same plane.

VI-3.5.2.6 When, during the measurement of discharge, the bed profile changes appreciably, depth measurements should be carried out by taking one depth reading at each point at the beginning and one at the end of the velocity measurement at each vertical, and the mean value of these two measurements should be taken as the effective depth.

NOTE: Inaccuracies in soundings are likely to occur due to the conditions below:

- (a) The deviation from the vertical of the sounding rod or line, particularly in deep water. A sounding line may deviate from the vertical owing to the force exerted by the stream on the line itself and on the sounding weight. The amount of deviation (drift) may be minimized by using a fine wire line (2.5-mm diameter or less) and a streamlined weight. Corrections to the indicated depth should be applied to compensate for the deviation;
- (b) The penetration of the bed by the sounding weight or rod. This difficulty may be alleviated by fitting a base plate;
- (c) The presence of boulders or large stones. The influence of these may be reduced by taking a number of soundings;

- (d) When an echo sounder is used, the presence of soft deposits may give rise to a double echo. The upper echo will normally give the effective depth but further investigations would be required. This difficulty may be eliminated by using an echo sounder whose operating frequency is 200 kHz or higher.

VI-3.5.2.7 When an ice cover exists, the effective depth should be computed, i.e. the depth of water beneath the ice cover.

NOTE: The total depth is measured at holes cut in the ice using an ice chisel, chain saw or ice drill and then the distance from the water surface to the bottom of the ice layer is measured using an L-shaped scale or similar device. The effective depth is computed by subtracting these two values.

VI-3.5.2.8 The uncertainty in the profile should not exceed  $\pm 2$  per cent or 0.1 m throughout the range of depths, whichever is greater.

### VI-3.6 Measurement of velocity

#### VI-3.6.1 Measurement by current meter

##### VI-3.6.1.1

- (a) The current meter should be held in the desired position in each vertical by means of a wading rod in the case of shallow channels, or by suspending it from a cable or rod from a bridge, trolley or boat in the case of deeper channels.
- (b) When a boat is used, the current meter should be held so that it is not affected by disturbances of flow caused by the boat.
- (c) After the current meter has been placed at the selected point in the vertical, it should be permitted to become adjusted to the flow before the readings are started.

NOTE: The meter used to measure the streamflow may be a rotating element current meter, an ultrasonic (acoustic) current meter, an electromagnetic current meter, a pendulum current meter, a pitot tube or any other suitable measuring instrument.

VI-3.6.1.2 At least 20 verticals should be used and the discharge in any one segment should not exceed 10 per cent of the total.

##### VI-3.6.1.3

- (a) The velocity at each selected point should be observed by exposing the current meter for a minimum of 30 seconds.
- (b) Where the velocity is subject to large periodic pulsations, the exposure time should be increased accordingly.

VI-3.6.1.4 The horizontal axis of the current meter should not be situated at a distance less than one-and-a-half times the rotor height from the water surface, nor should it be at a distance less than three times the rotor height from the bottom of the channel. Furthermore, no part of the meter should break the surface of the water.

VI-3.6.1.5 The current meter should be removed from the water for examination when passing from one vertical to another.

VI-3.6.1.6 When velocity observations are made from ice cover, the meter should be exposed to air temperatures for as short a time as possible in order to prevent formation of ice on moving parts. If ice does form, the meter should be soaked for a few minutes before commencing the count.

VI-3.6.1.7 If oblique flow is unavoidable, the angle of the direction of the flow to the perpendicular to the cross-section should be measured and the measured velocity corrected.

NOTE: If the measured angle to the perpendicular is  $\gamma$ , then  $v_{\text{corrected}} = v_{\text{measured}} \cos \gamma$

VI-3.6.1.8 The mean velocity of the water in each vertical should be determined by one of the standard methods.

NOTE: The standard methods are:

- (a) Velocity-distribution method;
- (b) Reduced-point methods:
- (i) Two-point method (measurement at 0.2 and at 0.8 of the depth below surface);
  - (ii) One-point method (measurement at 0.6 of the depth below surface);
- (c) Integration method;
- (d) Other methods:
- (i) Six-point method (measurement at 0.2, 0.4, 0.6 and 0.8 of the depth below surface and as near as possible below surface and above bottom);
  - (ii) Five-point method (measurement at 0.2, 0.6 and 0.8 of the depth below surface and as near as possible below surface and above bottom);
  - (iii) Three-point method (measurement at 0.2, 0.6 and 0.8 of the depth below surface);
  - (iv) Alternative one-point method (measurement at 0.5 of the depth below surface);
  - (v) Surface one-point method (measurement at one point just below surface).

#### VI-3.6.2 Measurement by floats

NOTE: Floats should only be used when it is impossible to employ a current meter because of excessive velocities or depths, because of the presence of material in suspension, or where velocities are too low for current meter measurement.

##### VI-3.6.2.1 Selection of cross-sections

- (a) Three cross-sections should be selected along the reach of the channel, at the beginning, midway and at the end of the reach.
- (b) The cross-sections should be far enough apart that the time of float movement from one cross-section to the next can be measured accurately.

NOTE: A minimum duration of float movement of 20 seconds is recommended.

### VI-3.6.2.2 *Measuring procedure*

- (a) The float should be released far enough above the upper cross-section to attain a constant velocity before reaching this cross-section.
- (b) The time at which the float passes each of the three cross-sections should be noted.
- (c) This procedure should be repeated with the floats at various distances from the bank of the river.
- (d) The width of the channel should be divided into segments of equal width or of approximately equal discharge.
- (e) The number of segments should not be less than three, but where possible a minimum of five should be used.

NOTE: Types of floats used are surface floats, double floats, subsurface floats and velocity rods (float rods).

- (f) Surface floats should be used when their movement is not likely to be affected by winds.
- (g) The length of the subsurface float should be approximately equal to the water depth, but the float should in no case touch the bottom.
- (h) The velocity rod should be at least 0.95 of the depth of the channel but should not touch the bottom.

### VI-3.6.2.3 *Evaluation of velocity*

- (a) The float velocity should be determined by dividing the distance between the cross-sections by the time taken by the float to travel this distance.
- (b) Several values of the float velocity should be taken and the mean of these values should be multiplied by the appropriate coefficient to obtain the mean water velocity.
- (c) The coefficient derived from current-meter measurements at the site at a stage as near as possible to that during the float measurement should be used for converting the float velocity to mean velocity.

NOTE: The following coefficients are given as general guidance:

- (a) 0.84 to 0.90 for surface floats, the higher values for smooth beds;
- (b) 1.0 for double floats at 0.6 of the depth and 0.96 at 0.5 of the depth;
- (c) 0.8 to 1.0 for subsurface floats and velocity rods.

### VI-3.7 **Dilution-gauging methods**

NOTE: Principle of method

A tracer liquid is injected into a stream and at a point further downstream, where turbulence has mixed the tracer uniformly throughout the cross-section, the water is sampled. The change in concentration between the solution injected and the water at the sampling station is a measure of the discharge. The tracer may be injected gradually (constant rate method) or suddenly (gulp, pulse or integration method) and may be chemical, radioactive or a fluorescent dye.

### VI-3.8 **Preliminary survey**

A preliminary survey should be carried out to determine the hydraulic and mixing characteristics of the site.

### VI-3.9 **Selection of site**

VI-3.9.1 At the site selected it should be possible to measure the whole range of discharge and all types of flow which may be encountered or which it is required to measure.

VI-3.9.2 There should be no loss or gain of water in the measuring reach.

VI-3.9.3 The length of the reach should be sufficient so that the solution injected at its beginning will be uniformly diluted throughout the sampling cross-section.

NOTE: It is desirable that the distance between the injection and sampling sections be as short as possible.

VI-3.9.4 A reach should be chosen in which the river is as narrow and as turbulent as possible, free of dead-water zones, with numerous transverse currents. Grassy and vegetation-grown zones, as well as separation zones of the river into arms, should be avoided.

NOTE: For determination of suitability and length of a measuring reach, a concentrated solution of dye fluorescein may be injected for a relatively short time at a point on the potential injection section. Study of the diffusion of the solution will show whether there are any dead zones and what should be the minimum distance between the injection and sampling cross-sections.

### VI-3.10 **Design and construction**

VI-3.10.1 The gauging station should consist of a measuring reach and a reference gauge.

VI-3.10.2 A station benchmark should be established to conform to the specifications given in section II of this annex.

VI-3.10.3 The reference gauge should conform to the specifications given in section II of this annex.

VI-3.10.4 The design and construction of the stilling well should conform to the specifications given in section II of this annex.

### VI-3.11 **Slope area method**

NOTE: Principle of method

The water-surface slope and the mean area of cross-section of the channel are measured in a selected reach which is as straight and uniform as possible. Assuming a coefficient of roughness, the mean velocity is computed using a flow formula relating velocity, roughness, hydraulic mean radius and slope. The discharge is then the product of mean velocity and mean area of cross-section of flow.

### VI-3.12 **Preliminary survey**

A preliminary survey should be made to ensure that the physical and hydraulic features of the proposed site are acceptable for the purpose of discharge measurement.

### VI-3.13 **Selection of site**

VI-3.13.1 The river should be fairly straight and uniform in section, free from obstructions and vegetation, show no progressive tendency to scour or accrete, and be free of the backwater effect of tributaries, downstream structures (dams, bridges), or tides.

VI-3.13.2 The length of the reach should be such that the difference in water levels is not less than 10 times the uncertainty in the difference in water levels.

VI-3.13.3 The flow should be contained within defined boundaries.

VI-3.13.4 The topographical survey should include a plan of the site, a longitudinal section of the channel from a point downstream of the control to the upstream limit of the reach, plus details of the channel, bed and flow characteristics.

### VI-3.14 **Design and construction**

VI-3.14.1 The gauging station should consist of a natural or artificial measuring section and two reference gauges.

VI-3.14.2 The positions of the cross-sections should be marked on the banks and the sections surveyed at intervals and after floods.

VI-3.14.3 A suitable access to the site should be constructed, where possible, to provide safe passage at all stages of flow and in all weather.

VI-3.14.4 All key points at the site should be permanently marked on the ground by markers sunk to such a depth below the surface as will ensure them against movement.

### VI-3.15 **Definite survey**

VI-3.15.1 After the gauging station has been constructed a definitive survey should be made.

VI-3.15.2 The gauges should be precisely levelled and the levels related to a common datum.

VI-3.15.3 The distance between the gauges should be accurately measured.

## VI-4 **Station for the measurement of discharge; regular measurements**

NOTE: The methods which follow are most suitable for relatively frequent measurements often made over a relatively long period and where a continuous record of discharge is desired.

### VI-4.1 **Stage-discharge station**

NOTE: Principle of method.

In a stable channel with satisfactory downstream control of water level there may be a unique relation between stage and discharge. In such channels it is expedient to establish the relation between stage and discharge and thereafter to deduce the discharge from measurements of stage only. The station may be calibrated by the velocity-area method using current meters, a moving boat, floats, or by dilution gauging methods.

### VI-4.2 **Preliminary survey**

VI-4.2.1 A preliminary survey should be made to ensure that the physical and hydraulic features of the proposed site conform to the requirements for the method selected to measure discharge for the calibration of the station.

VI-4.2.2 The proposed site should be in a stable stretch of river and free from standing waves at high flow, weed growth and adverse ice conditions.

### VI-4.3 **Selection of site**

VI-4.3.1 At the site selected it should be possible to measure the whole range of discharges and all types of flow which may be encountered or which it is required to measure.

VI-4.3.2 The site should be sensitive to the extent that a significant change in discharge, even for the lowest discharges, should be accompanied by a significant change in stage. The sensitivity of the station should be sufficient for the purpose for which the measurements are required.

VI-4.3.3 Sites where weed growth is prevalent should be avoided if possible.

VI-4.3.4 There should be no vortices, dead water or other abnormalities in flow.

VI-4.3.5 Sites where poor ice conditions are prevalent should be avoided if possible.

VI-4.3.6 Access to the site should be feasible under most conditions.

VI-4.3.7 The detailed topographical survey of the site should be made as specified under VI-3.1, VI-3.7 and VI-3.11 above, according to the method selected for measurement.

### VI-4.4 **Design and construction**

VI-4.4.1 The gauging station should consist of one or more natural or artificial measuring sections and a reference gauge.

NOTE: Normally a water-level recorder is installed to produce a continuous record of stage. It may be desirable to establish gauges at both banks, particularly when there is any evidence of difference in water level between the banks.

VI-4.4.2 The positions of each cross-section should be defined on the banks of the river by clearly visible and readily identifiable permanent markers, and a station benchmark should be established.

VI-4.4.3 If a control regulates the stage at low discharges at the gauging section, it should be situated at the downstream end of the reach and any measuring section should be sufficiently remote from it to avoid any distortion of flow which might occur in the vicinity.

VI-4.4.4 Where the main requirements necessary for a suitable gauging site, as specified, do not exist conditions should be improved, if possible, as follows:

- (a) Constructing flood banks to confine the flow in a defined floodway;

- (b) Trimming the bank to a regular line and a stable slope and removing from the bed any large stones or boulders to eliminate local eddies;
- (c) Protecting unstable banks upstream and downstream of a measuring section for a distance equal to at least one quarter of the bankfull width of the channel in each direction. In the case of float gauging the whole of the measuring reach should be protected;
- (d) Introducing an artificial control to improve the stage-discharge relation (sensitivity) or to create conditions in the measuring section for instruments to be effectively used.

NOTE: An artificial control is a simple structure built in a channel. It may be a low dam or a contraction which is seldom designed to function as a control throughout the entire range of stage. It is not practicable in large alluvial rivers.

VI-4.4.5 The reference gauge and water-level recorder should be located as close as possible to the measuring section and if floats are used to measure the velocities, the reference gauge and water-level recorder should be located near the midpoint of the measuring reach.

VI-4.4.6 A suitable access to the site should be constructed, where possible, to provide safe passage at all stages of flow and in all weather.

VI-4.4.7 All key points at the site should be permanently marked on the ground by markers sunk to such a depth below the surface as will secure them against movement.

VI-4.4.8 The reference gauge should conform to the specifications given in section II of this annex.

VI-4.4.9 The stilling well should conform to the specifications given in section II of this annex.

VI-4.4.10 The water-level recorder should conform to the specifications given in section II of this annex.

#### VI-4.5 **Definitive survey**

- (a) The definitive survey, repeated as required at not more than annual intervals, should include the accurate determination of the elevations and the relative positions of all the station installations and any other key points or significant features of the site. In case of stations affected by hysteresis, the rise and fall should be calibrated separately by discharge measurements, if the rate of rise (fall) is quite similar for all events.
- (b) Bed profiles should be checked after a flood.

#### VI-4.6 **Operation of station**

VI-4.6.1 Where a station is fitted only with a reference gauge or reference gauges and no water-level recorder, the local observer should be required to furnish readings at specified intervals of all the gauges in his or her care.

NOTE: Preferably the readings should be made at fixed hours. The intervals between the readings should be determined by the rate at which the water level at the site usually changes, but arrangements should be made to have additional readings when the water level is changing more rapidly than

usual. It is essential that the gauge observer records the exact time of each gauge observation.

VI-4.6.2 When a station is fitted with a recorder, visits by the observer should be made regularly to verify that the recorder is operating satisfactorily.

VI-4.6.3 Every gauging station should be inspected whenever any incident which might affect its accuracy is notified by the local observer.

VI-4.6.4 All recorders and recorder clocks should be cleaned and lubricated in accordance with the manufacturers' instructions or as indicated by experience under prevailing operating conditions.

VI-4.6.5 The elevation of all key points which were surveyed in the definitive survey should be checked by reference to the station benchmark at least annually or following any flood when equipment might have been damaged by debris or by ice. At the same time any vertical gauge should be tested for verticality.

#### VI-4.7 **Slope-stage-discharge or fall-discharge**

NOTE: Principle of method

In a stable channel with a varying downstream control of water level, when there is no unique relation between stage and discharge, there may be a relation between the water-surface slope, stage and discharge. In such channels it is expedient to measure both water-surface slope and water level from which the discharge is deduced. The station may be calibrated by the velocity-area method or by dilution-gauging methods.

#### VI-4.8 **Preliminary survey**

See VI-4.2 above.

#### VI-4.9 **Selection of site**

VI-4.9.1 At the site selected it should be possible to measure the whole range of discharges and all types of flow which may be encountered or which it is required to measure.

VI-4.9.2 At any gauging station with twin gauges, the site should be sensitive such that a significant change in discharge, even for the lowest discharges, should be accompanied by a significant change in stage at the gauges and/or fall between the two gauges. The sensitivity of the station should be sufficient for the purpose for which the measurements are required.

VI-4.9.3 Sites where weed growth is prevalent should be avoided if possible.

VI-4.9.4 There should be no vortices, dead water or other abnormalities in flow.

VI-4.9.5 Sites where poor ice conditions are prevalent should be avoided if possible.

VI-4.9.6 Access to the site should be feasible under most conditions.

#### VI-4.10 **Survey**

See VI-4.3.7 above.

### VI-4.11 **Design and construction**

VI-4.11.1 The gauging station should consist of one or more natural or artificial measuring sections and two water-level gauges, one of which is the reference gauge.

NOTE: Water-level recorders may be installed to produce a continuous record of stage and fall. It may be desirable to establish gauges at both banks, particularly when there is any evidence of difference in water level between the banks.

VI-4.11.2 The positions of each cross-section should be defined on the banks of the river by clearly visible and readily identifiable permanent markers and a station benchmark should be established.

VI-4.11.3 The length of the reach should be sufficient to make any observational error negligible relative to the fall of water level between the two gauges.

VI-4.11.4 If a control regulates the stage at low discharges at the gauging sections, it should be situated at the downstream end of the reach, and any measuring section should be sufficiently remote from it to avoid any distortion of flow which might occur in that vicinity.

VI-4.11.5 The reference gauge and water-level recorder should be located as close as possible to the measuring sections and, if floats are used to measure the velocities, the reference gauge and water-level recorder should be located near the midpoint of the measuring reach.

VI-4.11.6 Where the main requirements necessary for a suitable gauging site, as specified, do not exist conditions should be improved, if possible, as described in VI-4.4.4.

VI-4.11.7 Where not already existing, suitable access to the site should be constructed, if possible, to provide safe passage at all stages of flow and in all weather.

VI-4.11.8 All key points at the site should be permanently marked on the ground by markers sunk to such a depth below the surface as will secure them against movement.

VI-4.11.9 The reference gauge should conform to the specifications given in section II of this annex.

VI-4.11.10 The stilling wells should conform to the specifications given in section II of this annex.

VI-4.11.11 The water-level recorders should conform to the specifications given in section II of this annex.

### VI-4.12 **Definitive survey**

VI-4.12.1 The definitive survey, repeated as required at not more than annual intervals, should include the accurate determination of the elevations and the relative positions of all the station installations and any other key points or significant features of the site.

VI-4.12.2 Bed profiles should be checked after a flood.

### VI-4.13 **Operation of station**

See VI-4.6 above.

### VI-4.14 **Notches, weirs and flumes**

NOTE: Principle of method

A relation between head and discharge is established usually in the laboratory and this relation is applied to the field installation. A measurement of head only is therefore required at the gauging station and this value is inserted in the appropriate formula to obtain a value of discharge. The particular formula and conditions of application governing each measuring structure are specified in the *Manual on Stream Gauging* (WMO-No. 519). Whenever possible the formula should be verified in the field by discharge measurements.

### VI-4.15 **Preliminary survey**

A preliminary survey should be made of the physical and hydraulic features of the proposed site to check that it conforms (or may be constructed or modified so as to conform) to the requirements necessary for the measurement of discharge by the structure.

### VI-4.16 **Selection of site**

VI-4.16.1 Particular attention should be paid to the following features in selecting the site:

- (a) The adequacy of the length of channel of regular cross-section available (see note after VI-4.16.3);
- (b) The uniformity of the existing distribution;
- (c) The avoidance of a steep channel (Froude number should not exceed about 0.5);
- (d) The effects of any increased upstream water levels due to the measuring structure;
- (e) The conditions downstream including such influences as tides, confluences with other streams, sluice gates, mill dams and other controlling features such as seasonal weed growth) which might cause drowning;
- (f) The impermeability of the ground on which the structure is to be founded and the necessity for piling, grouting or other means of controlling seepage;
- (g) The necessity for flood banks to confine the maximum discharge to the channel;
- (h) The stability of the banks and the necessity for trimming and/or revetment;
- (i) Uniformity of section of the approach channel.

VI-4.16.2 The structure should be so designed that it cannot become drowned under specified operating conditions.

VI-4.16.3 The flow in the approach channel should have a symmetrical velocity distribution.

NOTE: This can most readily be ensured by providing a long straight approach channel of uniform cross-section. A length of approach channel five times the water surface width at maximum flow will usually suffice, provided the flow does not enter the approach channel with high velocity via a sharp bend or angled sluice gate.

### VI-4.17 Design and construction

VI-4.17.1 The gauging station should consist of an approach channel, a measuring structure including its associated upstream gauges, a downstream channel and a reference gauge.

NOTE: Normally a water-level recorder is installed to produce a continuous record of head.

VI-4.17.2 The control structures should be rigid and watertight and capable of withstanding flood-flow conditions without damage from outflanking or from downstream erosion. The axis should be in line with the direction of flow of the upstream channel.

VI-4.17.3 The surfaces of the flume throat and the immediate approach channel should be smooth.

VI-4.17.4 Vertical side walls to effect a contraction in plan should be symmetrically disposed with respect to the centre line of the channel.

VI-4.17.5 In order to obtain an acceptable uncertainty in the discharge, the tolerances in construction, which are given in the relevant International Standards,\* should be followed.

VI-4.17.6 The reference gauge should conform to the specifications given in section II of this annex.

VI-4.17.7 The zero of the head-measuring device should be accurately set initially with reference to the level of the invert of the crest or throat and this setting should be checked regularly thereafter.

VI-4.17.8 A station benchmark should be established to conform to the specifications given in section II of this annex.

VI-4.17.9 The design and construction of the stilling well should conform to the specifications given in section II of this annex.

VI-4.17.10 The water-level recorder should conform to the specifications given in section II of this annex.

### VI-5 Ultrasonic (acoustic) gauging station

NOTE: Principle of method

The principle of the ultrasonic (acoustic) method is to measure the velocity of flow at a certain depth in the channel by simultaneously transmitting pulses in both directions through the water from transducers located in the bank on each side of the river. The transducers may be designed to transmit and receive pulses. They are not located directly opposite each other but are staggered so that the angle between the pulse path and the direction of flow is between 30° and 60°. The difference between the time of travel of the pulses crossing the river in an upstream direction and those travelling downstream is directly related to the average velocity of the water at the depth of the transducers. This velocity can then be related to the average velocity of flow of the whole cross-section and, if desirable, the system can give a direct output of discharge by incorporating an area factor in the electronic processor.

\* ISO 1438, 3846, 3847, 4359, 4360, 4362, 4377 and the WMO *Manual on Stream Gauging* (WMO-No. 519).

### VI-5.1 Preliminary survey

A preliminary survey should be made to ensure that the physical and hydraulic features of the proposed site conform to the requirements for the application of the method.

### VI-5.2 Selection of site

VI-5.2.1 At the site selected it should be possible to measure the whole range of discharges and all types of flow which may be encountered or which it is required to measure.

VI-5.2.2 The following factors should be considered when selecting a site:

- (a) Mains power should be available;
- (b) There should be good access to the site, preferably to both banks;
- (c) Abrupt bends in the channel should be avoided if possible but these may be acceptable provided that condition (d) is satisfied;
- (d) At cross-sections in the area between the upstream and downstream transducer mountings, the velocity distribution should be similar;
- (e) The bed should preferably be stable;
- (f) The section should be free of weed growth which attenuates the acoustic signal;
- (g) The following table gives approximate minimum required depths of flow for rivers for three different frequencies. It is based on consideration of the refraction problem only and shows that the depth of water required increases as the path length increases. The table is based on the "first zero crossing" method of signal detection;

Path length (m)	Frequency, kHz		
	100	200	500
	Minimum depth necessary (m)		
50	0.8	0.6	0.4
100	1.2	0.8	0.5
200	1.7	1.2	0.8
300	2.1	1.5	0.9
400	2.4	1.7	1.1
500	2.9	1.9	1.2
600	3.0	2.0	1.3

- (h) Refraction of the acoustic signal can be caused by temperature gradients of the order of as low as 0.01°C per 30 mm depth and the signal may be lost due to this cause alone. A water-temperature survey should therefore be made at the proposed site — particularly during extremes of temperature;
- (i) Attenuation of the acoustic signal may also be caused by reflection and scatter of the propagated pressure

wave from entrained air bubbles. Sites immediately downstream of dams, weirs or waterfalls should therefore be avoided;

- (j) Suspended solids may have a significant effect on the signal attenuation, caused by both reflection and scatter from sediment particles suspended in the stream. Generally, sections having concentrations of over 1 000 mg/l for significant periods of time should be avoided. Due regard should be given to the operating frequency used, the size of sediment, distribution, water temperature and length of acoustic path.

### VI-5.3 Design and construction

VI-5.3.1 The gauging station should consist of:

- (a) (i) One or more pairs of transducers installed on each bank and fixed permanently in position;  
or  
(ii) One or more pairs of transducers installed on each bank and having the facility of movement in the vertical or on an incline;
- (b) An electronic console containing an electronic data processor and a data recorder;
- (c) A water-level recorder interfaced with the electronic data processor where an output of stage or discharge or both is required;
- (d) An armoured cable, to transmit the signals from the transducers and the water-level recorder (where part of the system), normally installed in the bed;
- (e) A reference gauge.

VI-5.3.2 A detailed level survey should be made of the bed and banks extending for one river width upstream of the proposed upstream transducer mounting and one river width below the downstream transducer mounting. If necessary, improvement of the bed and banks should be undertaken.

VI-5.3.3 When the positions of the transducer mountings have been decided, the angle between the mountings should be carefully surveyed for ultimate wiring into the electronic processor.

NOTE: The output from an ultrasonic station may be recorded in any one of the following modes:

- (a) Path velocity (or an index which is numerically proportional to the path velocity);
- (b) Path velocity and stage;
- (c) Discharge and stage;
- (d) Velocity and discharge;
- (e) Velocity, discharge and stage.

If stage is not included in the mode, it should be recorded separately by water-level recorder for subsequent off-site processing.

When operating in the discharge mode a manual facility should be provided in the electronic processor to make any adjustment necessary for a change in bed level.

VI-5.3.4 A reference gauge should conform to the specifications given in section II of this annex.

VI-5.3.5 A station benchmark should be established to conform to the specifications given in section II of this annex.

VI-5.3.6 The design and construction of the stilling well, if used, should conform to the specifications given in section II of this annex.

VI-5.3.7 The water-level recorder should conform to the specifications given in section II of this annex.

### VI-6 Compilation of records

VI-6.1 All field data should be examined critically and promptly with the objective of uncovering any anomalies which may exist.

VI-6.2 Where recorders are installed, readings of water levels from instrument charts or tapes should be taken at such intervals as may be necessary to define the hydrograph adequately. The conversion from water level to discharge should be made for each water level, making all necessary corrections.

VI-6.3 The extrapolation of discharges from rating curves should be avoided, if possible. Discharges derived by extrapolation should be distinguished from those derived by interpolation. (Methods for extrapolation are detailed in the *Manual on Stream Gauging* (WMO-No. 519), Volume II — Computation of Discharge, pages 16 to 26.)

NOTE: A record may be considered a standard record provided the sum of the estimated quantities does not exceed 5 per cent of the total runoff for the year.

VI-6.4 Annotations of the record should indicate any day on which the flow suffered interference through weed growth, ice or flood debris.

### VI-7 Measurement of discharge under ice conditions

#### VI-7.1 Design and construction

#### VI-7.2 Stilling well

The stilling well and inlet pipes should be constructed in such a manner that the system will remain operational during extended periods of freezing temperatures.

#### VI-7.3 The pneumatic recorder

VI-7.3.1 The orifice from which the compressed gas discharges into the stream should be mounted at an elevation below that of the bottom of the ice sheet which would normally form at the gauging station.

VI-7.3.2 The orifice should be located away from locations where anchor ice will form, such as above rapids, to prevent it being blocked up.

VI-7.3.3 Where the possibility of the orifice becoming frozen in the ice exists, the gas-feed pressure should be

reduced to a value less than the pressure equivalent of the full-scale range of the instrument.

VI-7.3.4 The line to the orifice should be buried in the bank to a depth sufficient to prevent damage from ice scour during the freshet.

VI-7.3.5 Where necessary, the instrumentation should be heated to the minimum operating temperature stated by the manufacturer if uninterrupted operation is required.

NOTES:

(a) The mercury used in some instruments solidifies at approximately  $-40^{\circ}\text{C}$ .

(b) Battery power supplies may be waterproofed and placed in the stream to obtain satisfactory performance during extremely low temperatures.

VI-7.4 **Notches, weirs and flumes**

VI-7.4.1 Where necessary and feasible, notches, weirs and flumes should be heated during the freezing period to ensure that the head-discharge relation is applicable during the winter.

VI-7.4.2 The elevation of the structures should be checked during or after the ice period to ensure the structure has not heaved due to freezing of the soil.



## VII – DETERMINATION OF THE STAGE-DISCHARGE RELATION

(See [D.1.2.] 3.4.1)

### VII-1 Scope and field of application

NOTES:

- (a) The material in this section of the annex is based on ISO 1100-2 (1998 and 2000) entitled "Liquid flow measurement in open channels — Part 2: Determination of the stage-discharge relation".
- (b) Detailed guidance on the determination of the stage-discharge relation and of the uncertainties involved is given in the *Manual on Stream Gauging* (WMO-No. 519).

This section specifies the methods of determining the stage-discharge relation at a gauging station for stable and unstable channels, including those subject to ice conditions as well as an analysis of the uncertainties involved in the preparation and use of the relation. The specifications are designed to conform to the requirements of Technical Regulation [D.1.2.] 3.1 and to meet the requirements for accuracy as indicated in Technical Regulation [D.1.2.] 3.6.

### VII-2 Calibration of a gauging station

#### VII-2.1 General

An established stage-discharge relation should be continuously reviewed so as to ensure its validity is maintained and to redetermine the relation when it is shown to have been significantly altered by any changes which have occurred.

NOTE: Since a river is continuously in course of development, its characteristics are subject to changes which may affect the calibration. These changes may take place gradually as a result of slow processes of erosion or accretion or they may occur suddenly as a consequence of alterations in the channel. In addition, temporary changes may be caused by the growth and decay of aquatic weeds, by the formation and breakup of ice cover or by the deposition of debris.

#### VII-2.2 Stable stage-discharge relation

NOTES:

- (a) The simplest expression of the stage-discharge relation is a plot on coordinate graph paper with discharges plotted as abscissae against corresponding stages as ordinates. Since discharge often ranges over several orders of magnitude, it is sometimes more convenient to plot the relation on single or double logarithmically divided paper. The stage used in

plotting should be the weighted mean stage during the discharge measurement.

- (b) Computation of mean stage of a discharge measurement is described in the *Manual on Stream Gauging* (WMO-No. 519), Volume I — Fieldwork, pages 147 to 150.

VII-2.2.1 A smooth curve should be drawn by eye through the array of data points to detect points which may be erroneous.

VII-2.2.2 The rating curve should be defined by a sufficient number of measurements suitably distributed throughout the entire range of water levels.

VII-2.2.3 The rating curve should be examined for hysteresis. Where possible the measurements should have been made at steady stage but, if not, those taken at rising or falling stages should be indicated by distinguishing symbols.

VII-2.2.4 The equation for the rating curve should be obtained, or the curve may be treated as a purely graphic record.

NOTE: If the zero of the gauge corresponds to zero discharge the stage-discharge relation at a station may often be expressed by an equation of the form  $Q = Ch^\beta$  (where  $Q$  is the discharge,  $h$  is the gauge height and  $C$  and  $\beta$  are coefficients) over the entire range of water levels, or more often by two or more similar equations, each relating to a portion of the range. If the zero of the gauge does not correspond to zero discharge a correction " $a$ " should be applied to  $h$  resulting in the equation:

$$Q = C(h + a)^\beta$$

The quantity  $a$  may be determined from the level on the control section in relation to zero flow. Alternatively, the constant  $a$  may be determined by trial and error while plotting  $Q$  (either on ordinary or on logarithmic scale), versus  $h + a$  (on logarithmic scale). The value of  $a$  which gives the best straight alignment of the data points may be considered as the best value of  $a$ .

#### VII-2.3 Unstable stage-discharge relation

##### VII-2.3.1 General

Smooth rating curves should be drawn for those periods when little or no shift is apparent.

NOTE: In unstable channels the channel geometry and friction properties — and hence the control characteristics — vary as a function of time and so does the stage-discharge relation at any given point in the channel. Such variations in control are evident particularly during and after flood periods, under ice conditions and during periods of weed growth and decay. In such cases, all discharges measured are plotted against their corresponding stages and each point labelled by date order.

### VII-2.3.2 **Shifting controls**

NOTE: The term “shifting control” refers to that condition where the stage-discharge relations do not remain permanent but vary from time to time, either gradually or abruptly, because of changes in the physical features forming the control for the station. If discharge measurements indicate that the stage-discharge relation has changed from a previous direction, one may use shifting-control corrections (addition or subtraction from the gauge height) in order that the effective gauge height corresponds to the measured discharge and rating curve.

### VII-2.3.3 **Shifting control due to ice conditions**

#### VII-2.3.3.1 **Discharge measurements and ice thickness**

- (a) Discharge measurements should be made before and after the formation of the ice cover to determine the initial decrease in discharge, at appropriate intervals to define the flow recession under the ice cover, and before and after the ice breakup to determine when the open-water stage-discharge relation becomes again applicable.
- (b) Ice thickness should be measured every time a discharge measurement is made.

#### VII-2.3.3.2 **Computation of daily discharge**

Daily mean discharges should be computed by means of a standard method.

NOTE: The most common standard methods are:

- (a) Using effective gauge heights and the open-water stage-discharge relation;
- (b) Direct interpolation between measured values of discharge;
- (c) Using the recession equation, particularly in larger streams having significant lake storage;
- (d) Using a winter rating curve, in particular if the ice regime appears to be consistent from winter to winter.

### VII-2.3.4 **Evaluation involving surface slope (fall)**

NOTE: For gauge sites affected by variable backwater and subject to hysteresis due to changing discharge when the hydraulic slope is very mild, the evaluation of discharge requires the use of the fall between two reference gauges located within the reach as an additional parameter. The plotting of the stage-discharge observations with the value of fall marked at each observation will reveal whether the relationship is affected by variable slope at all stages or only when the fall is smaller than a particular value.

VII-2.3.4.1 If the discharge is affected by the fall at all stages, the constant-fall method should be applied when evaluating the stage-discharge relation.

VII-2.3.4.2 If the discharge is affected by the fall only when the fall is smaller than a particular value, the normal-fall method should be applied when evaluating the stage-discharge relation.

NOTE: Methods for evaluating stage-discharge relations, using slope as a parameter, are described in the *Manual on Stream Gauging* (WMO-No. 519), Volume II — Computation of discharge, Chapter 2 and ISO 1100-2, Annex C.

### VII-2.4 **Extrapolation of the rating curve**

VII-2.4.1 A rating curve preferably should not be applied outside the range of observations upon which it is based.

VII-2.4.2 When extrapolation is necessary, the results obtained should be checked by more than one method.

### VII-2.5 **Rating table**

A rating table can be prepared from the rating curve(s) or from the equation(s) of the curve(s), showing the discharges corresponding to stages in ascending order and at intervals suited to the desired degree of interpolation.

### VII-3 **Methods of testing stage-discharge curves**

The rating curves should be tested for bias and goodness of fit.

NOTE: Methods of testing are given in the *Manual on Stream Gauging* (WMO-No. 519), Volume II — Computation of discharge, Chapter 2 and ISO 1100-2, Annex A.

### VII-4 **Uncertainty in the stage-discharge relation and in mean discharges**

#### VII-4.1 **Statistical analysis of the stage-discharge relation**

VII-4.1.1 The stage-discharge relation should be more accurate than any of the individual gaugings.

VII-4.1.2 The uncertainty in the stage-discharge relation should be expressed as  $E_{mr}$ , which is the confidence interval, at the 95 per cent level, as a percentage of the discharge calculated from the stage-discharge relation at each stage.

VII-4.1.3 If the stage-discharge relation contains one or more break points,  $E_{mr}$  should be calculated for each range.

VII-4.1.4 At least 20 observations should be available in each range before a statistically acceptable estimate can be made of  $E_{mr}$ .

NOTE: The procedure to evaluate the uncertainty in the stage-discharge relation  $Q = C(h + a)^\beta$  is as follows:\*

\*An example calculation for uncertainty in the stage-discharge relation is given in the *Manual on Stream Gauging* (WMO-No. 519), Volume II, Chapter I, pages 28 to 33.

- (a) The standard error of estimate is calculated for the logarithmic relation according to:

$$S_e(\ln Q) = \pm \left[ \frac{N-1}{N-2} \left[ S^2(\ln Q) - \beta^2 S^2(\ln(h+a)) \right] \right]^{1/2}$$

in which:

$S_e(\ln Q)$  is the standard error of estimate of  $\ln Q$ , expressed in absolute terms;

$N$  is the number of discharge measurements;

$S_{(x)}$  is the standard deviation of  $x$ ;

$\beta$  is the exponent of the stage-discharge relation;

$(h+a)$  is the stage.

- (b) The uncertainty  $E_{mr}$  is obtained by the formula:

$$E_{mr} = \pm t S_e(\ln Q) \left[ 1/N + \frac{[\ln(h+a) - \overline{\ln(h+a)}]^2}{\sum [\ln(h+a) - \overline{\ln(h+a)}]^2} \right]^{1/2}$$

in which:

$t$  should be taken as Student's  $t$  at the 95 per cent confidence level;

$E_{mr}$  is expressed as percentage of discharge..

- (c) The uncertainty in stage is computed as:

$$E_{(h+a)} = \pm \frac{100}{(h+a)} (E_g'^2 + E_z'^2)^{1/2}$$

where:

$E_{(h+a)}$  is the uncertainty in stage (or head);

$(h+a)$  is the stage (or head) (metres);

$E_g'$  is the random uncertainty in the recorded value of stage (or head) (metres) (recommended value for punched tape recorder =  $\pm 3$  mm; for chart recorder =  $\pm 5$  mm);

$E_z'$  is the random uncertainty in the gauge zero (metres) (recommended value =  $\pm 3$  mm).

## VII-4.2 Uncertainty In the mean discharges

VII-4.2.1 The daily mean discharge should be calculated by taking the average of the observations of discharge during the 24-hour period.

NOTE: The procedure to evaluate the uncertainty in the daily mean discharge is as follows:

- (a) For a velocity-area station:

$$E_{dm} = \pm \frac{\sum (E_{mr}^2 + \beta^2 E_{h+a}^2)^{1/2} Q_h}{\sum Q_h}$$

in which:

$E_{dm}$  is the uncertainty in the daily mean discharge;

$E_{mr}$  is the uncertainty in the stage-discharge relation;

$E_{h+a}$  is the uncertainty in the measurement of stage;

$Q_h$  are the values of discharges used to calculate the daily discharges;

$\beta$  is the exponent of the stage-discharge relation.

- (b) For a measuring structure:

$$E_{dm} = \pm \frac{\sum (E_c^2 + \beta^2 E_{h+a}^2)^{1/2} Q_h}{\sum Q_h}$$

in which  $E_c$  is the uncertainty in the coefficient of discharge.

VII-4.2.2 For monthly mean discharge:

$$E_{mm} = \pm \frac{\sum E_{dm} Q_{dm}}{\sum Q_{dm}}$$

in which:

$E_{mm}$  is the uncertainty in the monthly mean discharge;

$Q_{dm}$  is the daily mean discharge.

VII-4.2.3 For annual discharge:

$$E_a = \pm \frac{\sum E_{mm} Q_{mm}}{\sum Q_{mm}}$$

in which:

$E_a$  is the uncertainty in the annual discharge;

$Q_{mm}$  is the monthly mean discharge.



## VIII – ESTIMATION OF UNCERTAINTY OF DISCHARGE MEASUREMENTS

(See [D.1.2.] 3 7.1)

### VIII-1 Scope and field of application

NOTES:

- (a) The material in this section of the annex is based on ISO 5168 (2005) entitled "Measurement of fluid flow — Procedures for the evaluation of uncertainties."
- (b) Detailed guidance on the estimation of uncertainty of discharge measurements is given in the *Manual on Stream Gauging* (WMO-No. 519), Volumes I and II.

This section describes the calculations which should be performed in order to arrive at a statistical estimate of the interval within which the true discharge may be expected to lie, given a single discharge measurement, in order to support Technical Regulation [D.1.2.] 3.6.

### VIII-2 General principles

NOTE: It is physically impossible to effect a measurement without error. However, it is usually possible to assign an interval around the measurement, called the confidence interval,

within which the true value can be expected to lie with a prescribed probability, called the confidence level. There is a close relationship between the confidence level and the confidence interval such that the higher the level, the wider the interval. In this section, the 95 per cent confidence level is used.

### VIII-3 Nature of errors

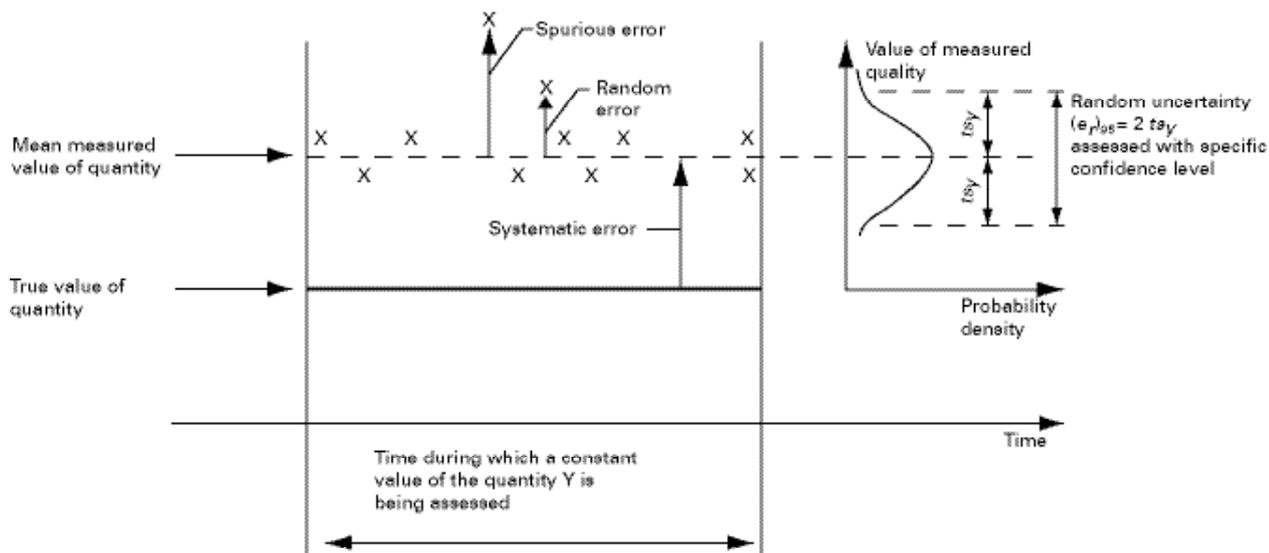
#### VIII-3.1 Classification of errors

Errors should be classified into the following three groups (see the figure below):

- (a) Spurious errors;
- (b) Random errors;
- (c) Systematic errors.

#### VIII-3.1.1 Spurious errors

Spurious errors should be eliminated by discarding the measurement.



NOTE: In order to identify spurious errors, a statistical “outlier” test, such as the one described in Annex A of ISO 5168, may be applied as a rejection criterion.

### VIII-3.1.2 **Random errors**

The uncertainty associated with random errors at the 95 per cent confidence level should be calculated as:

- (a)  $1.960\sigma_Y$  in case of a large number of measurements;
- (b)  $t\sigma_Y$  in case of a small number of measurements;

$\sigma_Y$  is the true standard deviation, estimated by the standard deviation  $s_y$  of the measurements of the variable  $Y$ ;  $t$  being a value of Student's  $t$  distribution.

NOTES:

- (a) Random errors are caused by numerous, small, independent influences. When measuring a certain quantity repeatedly, under equal conditions, the data points deviate from the mean in accordance with the law of chance, such that their distribution can be assumed to be normal. For a small sample of data points, the normal distribution should be replaced by the Student's  $t$  distribution. Tables of the  $t$  distribution can be found in most handbooks on statistics.
- (b) The random error in the result of a measurement can be reduced by making repeated measurements of the variable and using the arithmetic mean value, since the standard deviation of  $n$  independent measurements is  $\sqrt{n}$  times smaller than the standard deviation of the individual measurement.

### VIII-3.1.3 **Systematic errors**

#### VIII-3.1.3.1 **Minimizing uncertainties in systematic errors**

The uncertainty associated with systematic errors should be minimized by one of the following methods:

- (a) By changing equipment or conditions of measurement;
- (b) By subjective judgement.

NOTE: Systematic errors are those errors which cannot be reduced by increasing the number of measurements if the equipment and conditions of measurement remain unchanged.

#### VIII-3.1.3.2 **Correction for systematic errors**

If the systematic error has a unique, known value, this value should be added to (or subtracted from) the result of the measurement and the uncertainty in the measurement due to this source should be taken as zero.

### VIII-3.2 **Numerical values of uncertainties**

NOTE: Recommended values of component uncertainties for use in the computation of overall uncertainty in discharge measurement may be found in the *Manual on Stream Gauging* (WMO-No. 519), Volume I, sections 5.8 and 7.9.

### VIII-4 **Combination of errors**

If a quantity  $Q$  is a function of several measured quantities  $x$ ,  $y$ ,  $z$ , the error  $e_Q$  in  $Q$  due to errors  $e_x$ ,  $e_y$ ,  $e_z$  in  $x$ ,  $y$ ,  $z$ , respectively, should be evaluated by the equation:

$$(e_Q)^2 = \left(\frac{\partial Q}{\partial x} e_x\right)^2 + \left(\frac{\partial Q}{\partial y} e_y\right)^2 + \left(\frac{\partial Q}{\partial z} e_z\right)^2 + \frac{\partial Q}{\partial x} \cdot \frac{\partial Q}{\partial y} e_x \cdot e_y + \frac{\partial Q}{\partial x} \cdot \frac{\partial Q}{\partial z} e_x \cdot e_z + \dots$$

However, the terms  $\frac{\partial Q}{\partial x} \cdot \frac{\partial Q}{\partial y} e_x \cdot e_y$  etc. are covariance terms and their sum is considered negligible when compared with the squared terms since they contain quantities which are as equally likely to be positive or negative. Therefore, the error  $e_Q$  may be approximated by a simplified equation:

$$(e_Q)^2 = \left(\frac{\partial Q}{\partial x} e_x\right)^2 + \left(\frac{\partial Q}{\partial y} e_y\right)^2 + \left(\frac{\partial Q}{\partial z} e_z\right)^2$$

EXAMPLE:\* Uncertainty in velocity-area method

The channel cross-section under consideration is divided into segments by  $m$  verticals. The width, depth and mean velocity associated with the  $i^{\text{th}}$  vertical are denoted by  $b_i$ ,  $d_i$  and  $\bar{v}_i$  respectively. Then the computed discharge is:

$$Q = F_m \sum_{i=1}^m (b_i d_i \bar{v}_i)$$

in which the factor  $F_m$  approaches 1 when the number of verticals  $m$  increases. In actual calculations it is assumed that  $m$  is sufficiently large to make  $F_m \approx 1$ .

Random uncertainty

Introducing the notation  $E_{Fm} = (e_{Fm})/F_m$  for the relative uncertainty due to the limited number of verticals  $(E_{b_i})_r = (e_{b_i})_r/b_i$  for the relative random uncertainty in  $b_i$ , etc., then the total relative random uncertainty in the discharge measurement can be expressed by:

$$(E_Q)_r^2 \approx (e_{Fm})^2 + \frac{1}{m} \left[ (E_b)_r^2 + (E_d)_r^2 + (E_{\bar{v}})_r^2 \right]$$

In the derivation, the following simplifying assumptions have been made: the segment discharges  $b_i$ ,  $d_i$ ,  $\bar{v}_i$  are nearly equal and the uncertainties  $(E_{b_i})_r$ ,  $(E_{d_i})_r$  and  $(E_{\bar{v}_i})_r$  are nearly equal for all  $i$ 's and have the values  $(E_b)_r$ ,  $(E_d)_r$  and  $(E_{\bar{v}})_r$  respectively.  $(E_{\bar{v}})_r$  can be broken down further into:

$$(E_{\bar{v}})_r^2 = (E_p)_r^2 + (E_c)_r^2 + (E_e)_r^2$$

in which:

- $(E_p)_r$  is the percentage uncertainty due to the limited number of points in the vertical;
- $(E_c)_r$  is the percentage uncertainty of the current meter rating

\*A numerical example is given in ISO 5168, Section two, pages 21 and 22.

$(E_e)_r$  is the percentage uncertainty due to pulsations of flow.

Systematic uncertainty

The equation for calculating the overall percentage systematic uncertainty is:

$$(E_Q)_s^2 = (E_b)_s^2 + (E_d)_s^2 + (E_c)_s^2$$

in which:

$(E_b)_s$  is the percentage systematic uncertainty in the instrument measuring width;

$(E_d)_s$  is the percentage systematic uncertainty in the instrument measuring depth;

$(E_c)_s$  is the percentage systematic uncertainty in the current meter rating tank.

The overall uncertainty in a single discharge measurement (random and systematic uncertainties together) is then:

$$E_Q = \left[ (E_Q)_r^2 + (E_Q)_s^2 \right]^{1/2}$$

VIII-5

## Reporting of discharge measurements

A discharge measurement should be reported in one of the following forms:

(a) Uncertainties expressed in absolute terms

(i) Discharge  $Q = \dots\dots\dots$

Random uncertainty  $(e_r)_{95} = \dots\dots\dots$

Systematic uncertainty  $e_s = \dots\dots\dots$

(ii) Discharge  $Q = \dots\dots\dots$

(Overall) uncertainty  $\sqrt{(e_r)_{95}^2 + e_s^2} = \dots\dots\dots$

Random uncertainty  $(e_r)_{95} = \dots\dots\dots$

(b) Uncertainties expressed in percentage terms

(i) Discharge  $Q = \dots\dots\dots$

Random uncertainty  $(E_r)_{95} = \dots\dots\dots\%$

Systematic uncertainty  $E_s = \dots\dots\dots\%$

(ii) Discharge  $Q = \dots\dots\dots$

(Overall) uncertainty  $\sqrt{(E_r)_{95}^2 + E_s^2} = \dots\dots\dots\%$

Random uncertainty  $(E_r)_{95} = \dots\dots\dots\%$



## IX — FLOW MEASUREMENT USING FLUMES

(See [D.1.2.] 3.1.6)

### IX-1 **Scope and field of application**

NOTES:

- (a) The material in this section of the annex is based on ISO 4359 (1999) entitled "Liquid flow measurements in open channels — Rectangular, trapezoidal and U-shaped flumes".
- (b) Guidance on the determination of discharge is given in the *Guide to Hydrological Practices* (WMO-No. 168), the *Manual on Stream Gauging* (WMO-No. 519) and in *Use of Weirs and Flumes in Stream Gauging* (WMO-No. 280).

This section specifies the functional requirements for measurement of discharge using:

- (a) Rectangular-throated flumes;
- (b) Trapezoidal-throated flumes;

to conform to the requirements of Technical Regulations [D.1.2.] 3.1 and 3.6. U-throated, i.e. round-bottomed, flumes are seldom used for streamflow measurements, hence are not described in this section.

### IX-2 **Selection of type of flume**

IX-2.1 The type of flume should be selected on the basis of such factors as the range of discharge to be measured, the accuracy required, the head available and whether or not the flow carries sediment.

IX-2.2 The rectangular-throated flume, if necessary with a hump in the bed, should be used to measure discharge in channels with relatively small variation in flow.

IX-2.3 The trapezoidal-throated flume should be used where a wide range of discharge is to be measured with consistent accuracy and submergence is to be avoided.

### IX-3 **Selection of site**

The guidelines for selection of the site should conform to the specifications set out in section VI, VI-3.2 in general and VI-4.16 in particular, of this annex.

### IX-4 **Installation conditions**

IX-4.1 The complete measuring installation should consist of an approach channel, a flume structure and a downstream channel.

IX-4.2 The length of approach channel should be at least five times the water-surface width at maximum flow.

IX-4.3 If the width of the lined approach to the flume throat is less than the width of the channel, a contraction in plan should be provided.

IX-4.4 Flow conditions in the approach channel should be as specified in section V, V-3.1 of this annex.

### IX-5 **Flume structure**

IX-5.1 The structure should be rigid and watertight and capable of withstanding flood-flow conditions without damage from outflanking or downstream erosion.

IX-5.2 The centre line of the throat should be in line with the centre line of the approach channel.

IX-5.3 Subcritical flow should exist in the flume approach.

IX-5.4 The dimensions and height of the flume should be such that it will not be submerged and the downstream water level will not affect the discharge.

IX-5.5 The surface of the flume should be smooth (concrete, galvanized steel or other non-corrodible material).

IX-5.6 If the stream-bed downstream of the structure is erodible, the bed should be lined in order to avoid excessive scouring and thus avoid accumulation of bed material which may raise the water level sufficiently to drown the structure.

### IX-6 **Maintenance**

The structure should be maintained in the manner specified in section V, V-5 of this annex.

### IX-7 **Measurement of head**

IX-7.1 The head upstream of the flume throat should be measured by an appropriate water-level measuring device as described in section II of this annex.

IX-7.2 The head-measuring section should be located at a distance of between three and four times maximum head upstream of the leading edge of the entrance transition.

### IX-8 Rectangular-throated flume

There are three types of rectangular-throated flumes:

- (a) With side contractions only;
- (b) With bottom contraction (hump) only;
- (c) With both side and bottom contractions.

The type to be used depends on downstream conditions at various rates of flow, the maximum rate of flow, the permissible head loss and the limitations of the ratio of the head to the throat width, and whether or not the stream carries sediment.

IX-8.1 The following limits of application should be observed:

- (a) The lower limit of the head should not be less than 0.05 m or 5 per cent of the length of the throat, whichever is the greater;
- (b) The upper limit of the ratio of the areas of the throat and the approach channel should not exceed 0.7;
- (c) The width of the throat should be not less than 0.10 m;
- (d) The ratio of the head to the throat width should not exceed 3;
- (e) The head should not exceed 2 m;
- (f) The ratio of the head to the length of the throat should not exceed 0.50; for maximum head the ratio may be allowed to rise to 0.67, resulting in an additional uncertainty of 2 per cent;
- (g) To ensure modular (free) flow conditions the dimensions of the flume should be such that the total head upstream is at least 1.25 times that downstream at all rates of flow.

### IX-8.2 Computation of the stage-discharge relationship

IX-8.2.1 The stage-discharge relation for a particular flume should be obtained by considering a series of values of water levels (heads) and computing the corresponding discharges using the discharge equation:

$$Q = (2/3)^{3/2} (g)^{1/2} C_v C_d b h^{3/2}$$

where:

- $C_v$  is a coefficient allowing for the effect of approach velocity on the measured head upstream of the throat;
- $C_d$  is a coefficient allowing for the boundary effect on the measured values of  $b$  and  $h$ , including the effect of head losses (coefficient of discharge);
- $b$  is the width of the flume throat;
- $h$  is the head measured on the flume gauge.

The coefficients  $C_v$  and  $C_d$  are obtained from ready-made tables and diagrams which are given in the *Manual on Stream Gauging* (WMO-No. 519).

IX-8.2.2 The equation should always be checked against a few direct measurements obtained by other means (e.g. current meter). If the discharge values obtained from the equation deviate from the corresponding measured

discharge values, the coefficients of the equation should be adjusted accordingly. The acceptable deviation may be estimated as indicated in section VIII, VIII-3 of this annex.

### IX-9 Trapezoidal-throated flume

NOTE: Trapezoidal-throated flumes may be designed to cope with many different flow conditions, and the optimum throat geometry (i.e. bed width and side slopes) will depend on the range of flow to be measured and on the characteristics of the stream or channel in which it is to be installed.

IX-9.1 The following limits of application should be observed:

- (a) The lower limit of the head should not be less than 0.05 m or 5 per cent of the length of the throat, whichever is the greater;
- (b) The ratio of areas of the approach channel and the throat should be such that the Froude number,  $Fr$ , in the approach channel does not exceed 0.5 at any discharge; in some situations (for example when coarse sediment would deposit in the approach channel),  $Fr$  should be allowed to rise to 0.6, resulting in an additional uncertainty of 2 per cent for  $5 < Fr < 6$ ;
- (c) The bed width of the throat should be not less than 0.10 m;
- (d) The bed should not exceed 2 m;
- (e) At all elevations, the width between the throat walls should be less than the width between the approach channel walls at the same elevation;
- (f) The ratio of the head to the length of the throat should not exceed 0.50; for maximum head the ratio may be allowed to rise to 0.67, resulting in an additional uncertainty of 2 per cent;
- (g) To ensure modular (free) flow conditions at various throat expansions the dimensions of the flume should be such that the minimum ratio of the total head upstream to that downstream should be as follows:
  - (i) 1.10 for 1 in 20 each side;
  - (ii) 1.20 for 1 in 10 each side;
  - (iii) 1.25 for 1 in 6 each side;
  - (iv) 1.35 for 1 in 3 each side.

### IX-9.2 Computation of the stage-discharge relationship

NOTE: The discharge equation for the trapezoidal flume is expressed as follows:

$$Q = (2/3)^{3/2} (g)^{1/2} C_v C_s C_d b h^{3/2}$$

where:

- $C_v$  is a coefficient allowing for the effect of approach velocity on the measured head upstream of the throat;
- $C_s$  is a coefficient which takes into account the non-rectangular flow section;
- $C_d$  is a coefficient allowing for the boundary effect on the measured values of  $b$  and  $h$ , including the effect of head losses (coefficient of discharge);
- $b$  is the width of the flume throat at the bed;
- $h$  is the head measured on the flume gauge.

The direct application of this equation is not very convenient because the gauged head is different from the total head. A theoretical calibration for a range of discharge in one computation using a technique of successive approximation is therefore recommended.

#### IX-10 **Uncertainty of measurement**

The overall uncertainty of measurement should be estimated according to section VIII of this annex. The following factors should be taken into account:

- (a) The standard of construction and the finish of the flume surface;
- (b) The uncertainty of the formula for the coefficient for discharge;
- (c) The uncertainty of the velocity of approach coefficient;
- (d) A correct application of the installation requirements;
- (e) The uncertainty of measurement of the geometry of the flume;
- (f) The uncertainty of the measured head.



## X — DILUTION METHODS FOR MEASUREMENT OF FLOW

(See [D.1.2.] 3.1.7)

### X-1 Scope and field of application

NOTES:

- (a) The material in this section of the annex is based on ISO 9555-1 (1994) entitled "Measurement of liquid flow in open channels — Tracer dilution methods for the measurement of steady flow — Part 1: General", ISO 9555-2 (1992) entitled "Measurement of liquid flow in open channels — Tracer dilution methods for the measurement of steady flow — Part 2: Radioactive tracers", ISO 9555-3 (1992) entitled "Measurement of liquid flow in open channels — Tracer dilution methods for the measurement of steady flow — Part 3: Chemical tracers" and ISO 9555-4 (1992) entitled "Measurement of liquid flow in open channels — Tracer dilution methods for the measurement of steady flow — Part 4: Fluorescent tracers".
- (b) Detailed guidance on dilution methods is given in the *Guide to Hydrological Practices* (WMO-No. 168).

This section specifies the conditions and requirements for the use of dilution methods for measurement of discharge in open channels, to meet the requirements of Technical Regulations [D.1.2.] 3.1 and 3.6.

### X-2 Principle of method

NOTES:

- (a) A tracer liquid is injected into a stream and a sample(s) of water is (are) taken at a point downstream, where the tracer has been mixed uniformly throughout the cross-section. The dilution of the tracer is a measure of discharge.
- (b) The method is particularly suitable for measurement of discharges in turbulent streams where other methods do not apply.

At the sampling cross-section of the stream the tracer-water mixture must be absolutely complete and uniform.

### X-3 Characteristics of injected tracer

NOTE: The tracer may be a chemical or a fluorescent dye or a radioactive isotope and may be injected gradually (constant-rate method) or suddenly (gulp, pulse or integration method).

X-3.1 The tracer should comply with the following requirements. It should:

- (a) Dissolve readily in water at ordinary temperatures;
- (b) Not react with water, matter carried in solution and suspension, material which forms the channel or sampling systems or containers used in the analysis of the samples;
- (c) Only exist in the stream water at background levels which are known, relatively low and preferably stable with time;
- (d) Not be retained by sediments, plants or organisms, by stream-bed material or by containers and sampling systems used;
- (e) Be stable under environmental influences such as sunlight and pH changes in the measuring reach;
- (f) Not have any harmful effects on human and aquatic life in the concentrations used;
- (g) Be measurable with precision at concentrations compatible with the accuracy desired and with the quantity of tracer it is convenient to inject;
- (h) Be low in cost.

X-3.2 The handling of radioactive tracers and their use must conform with the regulations or decreed safety laws of the country concerned.

NOTE: Detailed guidance on this question is given in the IAEA *Guide to safe handling of radioisotopes in hydrology*, Safety Series No. 20.

### X-4 The measuring reach

X-4.1 A measuring reach should be as narrow and turbulent as possible, free of dead-water zones and with numerous transverse currents. Reaches with much aquatic growth and braided streams should be avoided.

X-4.2 The length of the measuring reach should be as short as possible but sufficient to assure a uniform dilution of the tracer at the sampling cross-section.

NOTES:

- (a) A first test of the suitability and length of the measuring reach can be made by injecting a concentrated solution of a strong dye, such as fluorescein, at the potential injection cross-section. A visual study of the diffusion of the dye will show whether there are any dead zones and what should be

the minimum distance between the injection and sampling cross-sections.

- (b) The mixing length, being a function of discharge, may be adequate for a moderate discharge but insufficient at lower or higher discharges.

X-4.3 There should be no loss or gain of water in the measuring reach.

NOTES:

- (a) Measurements can be made in case of inflow (tributaries or springs) into the measuring reach provided mixing is complete at the measuring cross-section. The measured flow then includes the inflow.
- (b) Measurements can be made if there is a loss in the measuring reach, provided that mixing is complete before the loss. The measured flow is then the flow upstream of the leakage and not at the sampling section.

## X-5 Sampling

NOTE: Sampling and monitoring of a tracer at the measuring cross-section can be done by discrete samples analysed in a laboratory or in situ by detection probes: conductivity or ion-detection electrodes for chemical tracers, fluorimeters for dye tracers and scintillation detectors for radioactive tracers.

### X-5.1 Constant-rate injection method

X-5.1.1 The tracer solution should be prepared in a separate tank with water from the stream to be measured and should be as homogeneous as possible.

X-5.1.2 This solution should be injected at a constant and measured rate of flow.

X-5.1.3 The measurement of injection rate should be made with a precision compatible with the required overall precision of discharge measurement.

X-5.1.4 The duration of injection should be such that a steady concentration regime is established in the measuring cross-section for a sufficient length of time, generally 10 to 15 minutes.

NOTE: The required duration generally varies directly with the length of the reach and the extent of the dead-water zones, and inversely to the mean velocity of the water.

X-5.1.5 Samples for determination of tracer concentrations should be taken:

- (a) Upstream of the point of injection;
- (b) Of the tracer solution to be injected;
- (c) In the measurement cross-section before the injection and when the concentration has attained a steady value, by continuous recording or by discrete sampling.

### X-5.2 Integration method

X-5.2.1 The appropriate quantity of concentrated tracer solution should be diluted with water from the stream in the injection vessel, and the exact volume of the solution should be known.

X-5.2.2 The injection should be made by pouring the contents of the container into the channel at the head of the measuring reach; the container should be rapidly rinsed with stream water and the washings transferred into the channel.

X-5.2.3 Samples should be taken:

- (a) Upstream of the injection cross-section before and after the injection;
- (b) Of the injection solution;
- (c) In the measuring cross-section before, during and after passage of the tracer either by continuous monitoring or by discrete sampling.

## XI — ECHO SOUNDERS FOR WATER DEPTH MEASUREMENTS

(See [D.1.2.] 3.1.3)

### XI-1 **Scope and field of application**

NOTE: The material in this section of the annex is based on ISO 4366 (1979) entitled "Echo sounders for water depth measurements".

This section provides information on the principles of operation, selection criteria, performance and use of echo sounders for measurement of water depths to conform with the requirements of Technical Regulation [D.1.2.] 3.1.

### XI-2 **Principle**

NOTE: An echo sounder indicates the depth of water by measuring the time differential between the transmission of an acoustic pulse and the reception of the echo from the stream-bed. Depth is determined from the equation:

$$d = \frac{tc}{2}$$

where:

- $d$  is the distance from the transducer to the stream-bed;
- $t$  is the travel time of the acoustic energy;
- $c$  is the velocity of sound in water.

Non-recording echo sounders indicate depth by a small flashing light on a depth scale; the analogue echo sounder gives a continuous trace of the stream-bed on a chart while in the digital echo sounder the instant depth appears on a display.

### XI-3 **Criteria for selection**

XI-3.1 An echo sounder whose operating frequency is 200 kHz or higher should be selected because it better discriminates abrupt changes in the stream-bed, and its beam is reflected from unconsolidated bed material instead of penetrating it.

XI-3.2 The beam width of the echo sounder transducer should be narrow (less than 10°) in order to detect clearly abrupt changes and steep inclinations in the stream-bed, and also to save battery power.

XI-3.3 When selecting echo sounders, the user should also consider the following:

- (a) The range of depths to be measured;
- (b) The anticipated nature of the stream-bed;
- (c) Where possible, the anticipated nature and the extent of suspended and other matter affecting the velocity of sound in water;
- (d) The desired accuracy of depth determination;
- (e) The minimum depth to which the echo sounder will respond and the smallest interval which may be read or recorded;
- (f) The anticipated accuracy of depth determination having regard to the following:
  - (i) Installation of the equipment with full and adequately illustrated instructions;
  - (ii) Operational procedure;
  - (iii) Maintenance routines;
  - (iv) Special requirements for control of equipment environment.

XI-3.4 In addition to the general features as given in section III of this annex, echo sounders should have the following other features:

- (a) A sensitivity control to adjust the signal for changes in water conditions and depth;
- (b) A control to correct for changes in the velocity of sound in water;
- (c) A clear and distinct display for the digital echo sounder which should be equipped with a shroud so that the digits can be read even in strong sunlight;
- (d) For analogue echo sounders (see also section XII, XII-4.1 of this annex):
  - (i) A recorder unit with a sufficiently wide chart so that the desired readability can be achieved;
  - (ii) Two or more selectable chart speeds so that the trace can be produced at a speed most suited for the application;
  - (iii) Indicator of "zero" or the initial point of signal transmission on the recorder;

- (iv) A mark switch so that the operator can insert a reference mark on the chart record.

#### XI-4 **Calibration**

XI-4.1 The echo sounder should be calibrated on site in order to produce accurate measurements.

XI-4.2 When accurate depth measurements are to be made, the sounder should be calibrated at least daily and more frequently if there are suspected changes in the water density or elasticity.

NOTE: The standard calibration method is to adjust the echo sounder to read a known depth correctly. This is usually accomplished by suspending on chains or cable a metal plate at a known depth below the transducer, ensuring that, the flat surface of the plate is parallel with the face of the transducer.

#### XI-5 **Precaution**

Echo sounders should be used with caution where the suspended-sediment concentration is high because one cannot be sure that the return signal received is from the bed. This also applies where the amount of entrained air is high, such as downstream of chutes, spillways or hydroelectric plants.

## XII — DISCHARGE MEASUREMENTS BY THE MOVING-BOAT METHOD

(See [D.1.2.] 3.1.8)

### XII-1 Scope and field of application

NOTES:

- (a) The material in this section of the annex is based on ISO 4369 (1979) entitled "Measurement of liquid flow in open channels — Moving-boat method".
- (b) Detailed explanation and guidance on the performance and computation of a discharge measurement by the moving-boat method are given in the *Guide to Hydrological Practices* (WMO-No. 168) and in the *Manual on Stream Gauging* (WMO-No. 519).

### XII-2 General

NOTES:

- (a) The moving-boat is essentially a velocity-area method of determining discharge. The stream is traversed along a preselected path normal to the flow. During the traverse the following data are collected:
  - (i) An echo sounder records the geometry of the cross-section (see section XI of this annex);
  - (ii) A continuously operating current meter measures the combined stream and boat velocities;
  - (iii) At intervals, the angle between the current meter, which aligns itself in a direction parallel to the movement of the water past it, and the preselected path is observed;
  - (iv) Alternatively to (iii), the distance from the boat to a fixed point on the bank and the corresponding time are measured at intervals.
- (b) Where practicable, readings of all the required parameters are automatically and simultaneously recorded.
- (c) There are two methods of calculating the stream velocity. Method 1 uses the data under (ii) and (iii), while method 2 makes use of the data under (ii) and (iv). In practice the two methods are often combined.

### XII-3 Measurement

XII-3.1 To compensate for minor deviations of the direction of flow or the deviations between the boat path and the cross-section, an equal number of runs should be made in both directions.

XII-3.2 The method should normally be used on wide rivers only, i.e. rivers more than 300 m wide and at least 2 m deep.

XII-3.3 If automatic and simultaneous readings of all required parameters are not recorded, readings should be made at 30 to 40 points in the cross-section for each run, depending on the width of the river. There should never be fewer than 25 readings.

XII-3.4 The minimum speed of the boat should be of the same order as the velocity of the stream.

XII-3.5 The stream should not have undercurrents, as can be the case in tidal flow.

### XII-4 Equipment

NOTE: The following specialized instrumentation is required for the moving-boat method:

- (a) Strip chart (analogue) echo sounder;
- (b) Modified propeller-type current meter;
- (c) Pulse-rate indicator with counter and display unit;
- (d) Vane and angle indicator;
- (e) Optical or electronic range finder;
- (f) Boat with outboard engine.

XII-4.1 The echo sounder should be portable, of high quality and should have a resolution of at least 0.10 m accurate to 1 per cent of full operating range. It should conform to the specifications given in section XI of this annex.

XII-4.2 The current meter should be equipped with a component propeller. It should be adapted for mounting on the leading edge of the vane or for suspending on a cable from the boat.

NOTE: When applying method 2, the angle between the cross-section and the current meter axis is not needed. Thus, the current meter may be suspended on a cable from the boat. The suspension equipment should conform to specifications given in section III of this annex.

XII-4.3 The revolutions of the current meter should be displayed on a counter or converted to a velocity display. The counting unit should have provision to preset the

number of pulses. An audible signal should be generated when the preset number is reached and the echo sounder strip chart should be automatically marked. The counter should automatically reset itself before repeating the process.

XII-4.4 A vane assembly with angle indication mechanism should be mounted on the bow of the boat. The angle between the direction of the vane and the course of the boat (i.e. the cross-section line) should be indicated on a dial which should be calibrated in degrees from 0° to 90° on both sides of its index point. The vane with current meter should be mounted so that they extend 0.9 to 1.2 m below the water surface, depending on the depth of the river.

XII-4.5 The distance from each observation point (vertical) to a fixed position on the river bank should be measured by an optical or electronic range finder. The range finder should have a relay connection with the echo sounder so that at each observation point a line marking can be triggered on the strip chart, automatically or by hand.

XII-4.6 The boat and the outboard engine should be matched. The boat should be stable and easily manoeuvrable, and it should be suited to the local river conditions.

## XII-5 **Measuring site**

XII-5.1 The criteria for the selection of the measuring site should conform with the specifications given in section VI, VI-3.2 of this annex, as applicable.

XII-5.2 The path selected for the boat to traverse the river should be as nearly perpendicular to the flow direction as possible. This path should be marked on each bank by a pair of clearly visible range markers placed in line with the path.

NOTE: Spacing between the two markers on each bank is dependent upon the length of the traverse. Approximately 30 m of spacing is required for each 300 m of path length.

XII-5.3 Anchored floats to mark the beginning and ending points of the traverse should be placed in the stream 12 to 15 m from each shore along the selected path.

## XII-6 **The crew**

There should be two or three experienced crew members, depending on the level of automatic recording equipment, when making a moving-boat discharge measurement. Normally, they include a boat operator, an angle or distance observer and a notekeeper. The notekeeper should be the person in charge of the measurement.

## XII-7 **Computation of discharge**

XII-7.1 The discharge should be computed as specified in the *Manual on Stream Gauging* (WMO-No. 519).

XII-7.2 The average cross-section coefficient used to adjust the computed discharge should be calculated from a few representative vertical-velocity curves taken across the measuring cross-section.

## XIII — WATER QUALITY MONITORING

(See [D.1.5.] 1)

### XIII-1 **Monitoring objectives**

XIII-1.1 A water quality monitoring programme should clearly define the objectives of the programme.

XIII-1.2 The objectives should be based on existing legislation and/or policy directives; on national, regional and organizational priorities; and on a reasonable assessment of available resources (human, financial and material).

XIII-1.3 The objectives should be, as far as possible, product oriented, i.e. should have an identifiable output, such as interpretative report, water quality standards or pollution control measures.

XIII-1.4 The objectives should specify time limits. They can be long or short term. Long-term objectives are usually achieved by establishing a network in which samples are collected at regular intervals, e.g. monthly, bimonthly or seasonally, over a long period of time, i.e. of at least 10 years. Short-term objectives are usually achieved by conducting special intensive studies characterized by frequent sampling over short periods of time.

XIII-1.5 Possible long-term objectives are to:

- (a) Increase knowledge of existing water quality conditions and understanding of the aquatic environment;
- (b) Determine the availability of water quantity and quality, i.e. a quantity-quality inventory of water resources;
- (c) Provide information on the past, present and future effects of significant natural and anthropogenic activities on the aquatic environment, including water projects such as dams, diversions, stream enlargement, massive irrigation projects and aquifer flooding, and agricultural, industrial and urban developments;
- (d) Monitor pollution systems, such as industrial complexes, urban areas, mineralized water and sea water, to safeguard water supplies;
- (e) Assess the effectiveness of pollution control measures;
- (f) Detect trends in water quality to provide an early warning system.

XIII-1.6 Possible short-term objectives are:

- (a) Identification of problem areas;
- (b) Identification of sources of pollutants and their loads;

- (c) Determination of compliance with regulations and standards;
- (d) Monitoring of interjurisdictional water quality;
- (e) Research on processes and pathways.

### XIII-2 **Network design**

XIII-2.1 The network design should be based on the monitoring objectives. It consists of:

- (a) Selection of sampling sites;
- (b) Selection of physical, chemical and biological parameters to be measured in situ, in the field and in the laboratory;
- (c) Selection of media (i.e. water, sediment, biota) and type of samples (e.g. grab, integrated, composite) to be collected for analysis;
- (d) Determination of sampling frequency;
- (e) Determination of sampling collection, preservation, transport, analytical and data handling methodologies;
- (f) Determination of quality assurance protocols for field, laboratory, and data storage and retrieval activities;
- (g) Determination of analysis requirements and selection of methods;
- (h) Determination of requirements and selection of interpretation products, e.g. reports, fact sheets, models.

#### XIII-2.2 **Selection of sampling sites**

XIII-2.2.1 The selection of sampling sites should follow from the objectives established for the monitoring programme.

NOTES:

- (a) If the purpose of the monitoring programme is to monitor the quality of drinking water supplies, then the sampling will concentrate on the proximity of the intake for the water treatment plants. If the purpose is to establish the effects of long-range transport of airborne pollutants (LRTAP), the sites will be located in areas remote from anthropogenic activities. If the objective is to enforce or monitor compliance with certain regulations or laws, then the protocols specified in the legislation should be followed.

- (b) For selection of sampling sites for monitoring long-range transport of airborne pollutants see XIII-4.4 below.

XIII-2.2.2 Other factors which should be considered in establishing a water quality sampling site are:

- (a) Accessibility and safety of the site;
- (b) Availability of other measurements at the site, e.g. river discharge or precipitation quantity and quality (especially when studying LRTAP effects);
- (c) Degree of cooperation from other agencies if this cooperation is significant for the programme, e.g. will provide samples or measurements impossible to obtain otherwise, or will reduce the overall costs;
- (d) Costs of sampling, and costs and time for sample transport to the laboratory;
- (e) Availability of prior water-quality data;
- (f) Land use;
- (g) Location of inputs (point and non-point sources) in relation to the water bodies being studied.

### XIII-2.3 Selection of water quality parameters

XIII-2.3.1 Water quality parameters can be classified by their nature as:

- (a) Physical properties, e.g. temperature, colour, turbidity, electrical conductivity;
- (b) Inorganic chemical components, e.g.:
  - gases —  $O_2$ ,  $NH_3$ ;
  - major ions —  $Cl^-$ ,  $SO_4^{2-}$ ,  $HCO_3^-$ ,  $CO_3^{2-}$ ,  $Na^+$ ,  $Mg^{2+}$ ,  $Ca^{2+}$ ;
  - nutrients — N and P compounds;
  - trace metals — e.g.  $Cd^{2+}$ ,  $Pb^{2+}$ ,  $Zn^{2+}$ ;
  - general measurements, e.g. alkalinity, pH, total dissolved solids;
- (c) Organic substances, e.g.:
  - pesticides, herbicides;
  - polyaromatic hydrocarbons (PAHs);
  - polychlorinated biphenyls (PCBs);
  - phenols, chlorinated phenols;
  - volatile organic compounds (VOCs);
- (d) Biological components, e.g.:
  - microbiological — coliforms;
  - plankton, chlorophyll, biomass;
  - fish.

XIII-2.3.2 The basic water quality parameters which should be monitored are listed in the table below. Water quality parameters to be measured in a monitoring programme should be based on:

- (a) Objectives of the programme;
- (b) Costs of sample collection and analysis;
- (c) Resources available (e.g. money, personnel, field equipment and instrumentation, laboratory facilities);
- (d) Methods available for sample collection, preservation, quality assurance and analysis;

- (e) Existing knowledge of water quality of the water bodies under study, such as their chemical composition or any relationships between variables;
- (f) Geochemistry of the region under study;
- (g) Land use;
- (h) Production or use of chemicals in the region;
- (i) Physical, chemical and biological nature of inputs to the water bodies.

### XIII-2.4 Media selection

XIII-2.4.1 The objectives of the programme are the main factors in deciding what materials, e.g. water, suspended sediment, bottom sediment or biota, should be collected for physical, chemical and biological analysis.

NOTE: If the objective of the programme is to monitor the quality of drinking water supplies, then the water column should be sampled. If the objective is to find out what chemicals are present in a given aquatic system, then all media, i.e. water, suspended and bottom sediments and biota, should be sampled, as some substances can be detected only in some media.

XIII-2.4.2 Other factors which should be considered in deciding which media to sample are the availability of:

- (a) Sampling methods and equipment;
- (b) Analytical methods for particular media compatible with the objectives of the programme.

### XIII-2.5 Determination of sampling frequency

XIII-2.5.1 Sampling frequency depends on:

- (a) The purpose of the network (e.g. the type and magnitude of change to be detected);
- (b) The range of the measured variables;
- (c) The time variability of the parameters of interest;
- (d) The availability of resources for sample collection, preservation, transport to the laboratory, sample analysis, data storage and retrieval, quality assurance and data interpretation.

NOTE: If the purpose of the network is to determine the average (yearly, monthly, weekly, ...) value of a parameter with standard deviation  $S$  and an error  $E$  at a degree of certainty, statistical considerations require the number of (yearly, monthly, weekly, ...) samples to be:

$$m \geq \frac{t_{1/2} \cdot S^2}{E}$$

where  $t_{1/2}$  is the Student's  $t$  constant (see also the *Manual on Water Quality Monitoring* (WMO-No. 680), section 2.4).

XIII-2.5.2 The time variability of water quality parameters can be determined by:

- (a) Using existing water-quality data; or
- (b) Carrying out a preliminary (pilot) sampling programme.

## NOTES:

- (a) To ensure the effectiveness and efficiency of a network design with respect to the objectives of the study, it is recommended that the design be tested and assessed by means of a pilot programme or during the initial operation of the network.
- (b) Assumptions about the temporal and spatial homogeneity of a river or lake should be tested by cross-sectional and vertical sampling at some representative locations.
- (c) Estimates of standard deviation and error can be obtained during pilot projects which can improve project planning.
- (d) Additional data requirements for completion of project objectives can be identified in pilot projects.

### XIII-3 Collection of surface water samples

XIII-3.1.1 Grab or discrete: sample taken at a selected location, depth and time.

XIII-3.1.2 Depth-integrated grab: sample collected over a predetermined part or over the entire depth of a water column, at a selected location and time.

XIII-3.1.3 Composite: sample obtained by mixing several discrete samples of equal or weighted volumes in one container, an aliquot of which is then analysed for the constituents of interest, or by continuously sampling a flow. A composite sample provides an estimate of average quality over the period of sampling. There are two main types of composite sample:

- (a) Sequential or time composite made up by:
- continuous, constant sample pumping; or
  - mixing equal water volumes collected at regular time intervals;
- (b) Flow proportional composite obtained by:
- continuous pumping at a rate proportional to the flow;
  - mixing equal volumes of water collected at time intervals which are inversely proportional to the volume of flow; or
  - mixing volumes of water proportional to the flow collected during regular time intervals.

XIII-3.1.4 The type of surface water sample to be collected is determined by:

- (a) The objectives of the study, including the parameters of interest and the precision and accuracy needed;
- (b) The characteristics of the system being studied, including the flow regime, tributaries, groundwater infusions, homogeneity of the body of water, climatic conditions, anthropogenic inputs, and the aquatic life present;
- (c) The resources available (i.e. personnel, equipment and materials).

XIII-3.1.5 The collection of grab samples is appropriate when it is desired to:

- (a) Characterize water quality at a particular time and location;
- (b) Provide information about approximate range of concentrations;

### Basic parameters\*

	Rivers	Lakes and reservoirs	Groundwater
Temperature	X	X	X
pH	X	X	X
Electrical conductivity	X	X	X
Dissolved oxygen	X	X	X
Nitrate	X	X	X
Nitrite	–	–	X
Ammonia	X	X	X
Calcium	X	X	X
Magnesium	X	X	X
Sodium	X	X	X
Potassium	X	X	X
Chloride	X	X	X
Sulphate	X	X	X
Alkalinity	X	X	X
BOD	X	X	–
Total suspended solids	X	X	–
Chlorophyll a	–	X	–
Transparency	–	X	–
Orthophosphate	X	X	–
Total phosphorus (unfiltered)	X	X	–

\* This table is based on the *GEMS/WATER Operational Guide* of the Global Environmental Monitoring System (GEMS) (UNEP, WHO, UNESCO, WMO), 1978.

- (c) Allow collection of variable sample volumes;
- (d) Deal with a stream which does not flow continuously; or
- (e) Detect changes of water quality based on relatively short time intervals.

## NOTES:

- (a) For sampling sites located in a homogeneous reach of a river or stream, the collection of depth-integrated samples in a single vertical may be adequate. For small streams, a grab sample taken at the centroid of flow is usually adequate.
- (b) For sampling sites located in a non-homogeneous reach of a river or stream, it is necessary to sample the channel cross-section at a number of points and depths. The number and type of samples taken will depend on the width, depth, discharge, amount of suspended sediment, and aquatic life present. Generally, the more points sampled in the cross-section, the more representative the composite sample will be. Ten verticals are recommended although three to five are sometimes sufficient, and fewer are necessary for narrow and shallow streams. The location of the verticals can be determined by:
  - The EWI (equal-width increment) method — verticals spaced at equal intervals across the stream; or
  - The EDI (equal-discharge increment) method — the cross-section is divided into segments of equal discharge. This method requires detailed knowledge of the stream flow distribution in the cross-section.

### XIII-3.2 General sampling guidelines

XIII-3.2.1 The sample collector should be prepared for the methods required by different sampling sites and the time of the year, e.g.:

- (a) Shallow water and deep water;
- (b) Sampling from boats, bridges, aircraft, or from stream banks and wharves;
- (c) Special conditions such as flooding, snow cover, or ice cover.

XIII-3.2.2 Large non-homogeneous particles such as leaves and detritus should not be included in the sample.

XIII-3.2.3 Samples from a river should be taken facing upstream.

NOTE: This enables the collector to see whether any floating debris is coming downstream. It also avoids contamination from oil, paint chips or other dirt from the sampling site.

XIII-3.2.4 A sufficient amount of water, sediment or biota should be collected to permit replicate analyses and quality control testing, if required. If not otherwise specified, the required amount is a summation of the quantities required for analysis of all the parameters of interest.

XIII-3.2.5 Accurate records of the sampling conditions should be maintained, including possible sources of interference, atmospheric conditions and a description of any unusual observations at the location.

### XIII-3.3 Field sampling equipment

XIII-3.3.1 Grab water samples should be taken with a recognized sampler.

NOTES: Examples of suitable samplers are:

- (a) Sampling iron with an appropriate bottle;
- (b) Van Dorn bottle;
- (c) Kemmerer bottle;
- (d) Pump-type sampler;
- (e) Multiple sampler.

A solvent-cleaned bottle opened just below the surface can be used.

XIII-3.3.2 Depth-integrated samples should be obtained by:

- (a) Filling a bottle at a constant rate while moving it vertically at a constant rate, such that the bottle is just filled at the end of the vertical motion; or
- (b) Lowering a flexible plastic tube weighted at the bottom end to the desired depth, closing the upper end, raising it and draining the contents into a sample container.

XIII-3.3.3 Composite samples should be obtained by:

- (a) Mixing several grab samples; or
- (b) Pumping of water over a period of time.

XIII-3.3.4 Automatic samplers should be used to collect either grab or composite samples at predetermined times, predetermined time intervals, or at a given rate of flow into the sampling bottle.

### XIII-3.4 Preparation for field trips

Thorough preparation should be made before setting forth on a field trip. This includes:

- (a) Specific instructions on sampling procedures;
- (b) Preparation of an itinerary according to the sampling schedule;
- (c) Preparation of lists of equipment and materials;
- (d) Ensuring that all sample bottles have been cleaned in accordance with standard procedures;
- (e) Ensuring that the chemical reagents and standards have been provided by the laboratory;
- (f) Preparation of a checklist.

NOTES:

- (a) The number and size of containers needed are determined by the number of parameters to be analysed, the sample volumes prescribed by the laboratory, and the number of duplicate and triplicate analyses required by quality assurance.
- (b) The type of containers used depends on the parameter being measured. Polyethylene containers are the most economical. Glass, Teflon, or special containers are used for

very sensitive parameters such as dissolved oxygen or highly reducing interstitial water.

- (c) A well-prepared checklist ensures that nothing is forgotten. It should include items such as: checking and calibration of instruments; supplies of sample containers; filters; ice chests; supplies of reagents for preservation; field analysis and standardization; maps; station descriptions; container labels and station reporting forms; manuals; tools; spare parts; safety equipment; first aid kit.

### XIII-3.5 Field measured parameters

XIII-3.5.1 Rapidly changing parameters should be measured in the field. These include temperature, colour, transparency, turbidity, pH, dissolved oxygen, and conductivity, and, in the case of groundwater, redox potential.

XIII-3.5.2 Because field measurements involve electrical meters, titrations and optical comparisons, field personnel should be trained to maintain such apparatus and to use it exactly and reproducibly as specified in the *Manual on Water Quality Monitoring* (WMO-No. 680).

XIII-3.5.3 Careful cleaning of containers and apparatus, appropriate to each kind of analysis, is essential for reliable analytical results, together with avoidance of contamination such as dust, dirt, smoke, fumes, fingers and grease while samples are being taken and handled.

XIII-3.5.4 In no case should a value of zero be recorded for an analytical result; if the value obtained is below the method detection limit, it should be recorded as "less than (state the method detection limit)".

### XIII-3.6 Recording of field data

XIII-3.6.1 An accurate record should be made of the location at which each sample was taken and of any special conditions prevailing at the time of sampling.

XIII-3.6.2 When a sampling station is established its location should be adequately described.

NOTE: In addition to recording its geographical coordinates (latitude and longitude, grid reference, Universal Transverse Mercator, etc.), it should be located by means of a large-scale map of the area, a detailed sketch of the locale, and measured distances from nearby landmarks and permanent reference points. The registered description should include natural and man-made conditions which may have a bearing on water quality.

XIII-3.6.3 Station numbers or codes should be established for ease of reference to station locations on sample labels.

XIII-3.6.4 A field sheet of observations should be prepared, including location, date, time, measurements made, and notes of any conditions which may make a difference in interpreting the data, such as weather, dead fish, algal growth, ice breakup and water flow data. The field sheet should also show which methods of analysis have been used, field calibrations of instruments including make and model number, sampling apparatus used and procedures, and specifics of quality control.

## XIII-4 Water quality sample collection and storage

### XIII-4.1 Types of samples

XIII-4.1.1 The types of samples considered in XIII-4 are:

- (a) Surface water samples, for physico-chemical analysis (see XIII-3 for sampling methods);
- (b) Samples for biological analysis;
- (c) Samples of atmospheric deposition for chemical analysis;
- (d) Samples of suspended or bottom sediment;
- (e) Groundwater samples.

### XIII-4.2 Field filtration and preservation

XIII-4.2.1 To distinguish between concentrations of components dissolved in the water and of components present in or adsorbed on suspended particulate matter, samples with turbidity greater than three should be filtered in the field. Particular attention should be given to field filtration to avoid contamination of the sample.

XIII-4.2.2 The choice of appropriate containers is very important in preserving the integrity of samples. Consideration should be given to:

- (a) Leaching of container material by the sample, e.g. organic compounds from plastic, sodium or other ions from glass;
- (b) Sorption of substances from the sample onto container walls, e.g. trace metals, especially radioactive species, by glass, and organic substances by plastic;
- (c) Direct reaction of the sample with the container, e.g. fluoride and glass;
- (d) Bacteriostatic effects of metals and rubber.

XIII-4.2.3 For a number of parameters, samples should be preserved for the trip to the laboratory by chemical additions, such as acidification, by refrigeration, by sequestering of metal ions, by staining of some organisms, and in some cases by freezing.

### XIII-4.3 Biological samples

XIII-4.3.1 Microbiological samples should be collected in sterile, autoclavable non-toxic bottles.

XIII-4.3.2 Samples which cannot be analysed immediately should be stored in the dark in melting ice to minimize multiplication and die-off of the micro-organisms.

XIII-4.3.3 Macrobiodota require specific sampling devices, depending on the types of organisms, and on whether they are in the water column or in the sediment:

- (a) Fish — actively with seines, trawls, electro-fishing, chemicals, and hook and line, or passively with nets and traps;
- (b) Macroinvertebrates — with nets, multiple-plate samplers and basket samplers;

- (c) Plankton — with surface water samplers, or specially designed equipment such as Juday traps or metered nylon nets;
- (d) Periphyton — with anchored or floating slides;
- (e) Macrophytes — with rakes, dredges, cutting knives on poles, grapples, or in some case with the aid of self-contained underwater breathing apparatus;
- (f) Bottom dwellers — see XIII-4.5.

#### XIII-4.4 Samples of atmospheric deposition

XIII-4.4.1 Site selection for sampling for monitoring the long-range transport of airborne pollutants should consider the direction and distance of transport controlled by short-term weather conditions and by long-term climate. For large areal scale monitoring, sites should be rural and remote, with no continuous sources of pollution within 50 km in the direction from which the prevalent wind originates, and 30 km in all other directions.

XIII-4.4.2 Local site-selection criteria should include:

- (a) No moving sources of pollution such as traffic within 1 000 m of the site;
- (b) No surface storage of agricultural products, fuels or other foreign materials within 1 000 m of the site;
- (c) Installation on flat, undisturbed land, preferably grass-covered, with no wind-activatable sources of pollution nearby such as ploughed fields, unpaved roads, or natural or man-made sources of turbulence and eddy currents;
- (d) No objects such as trees or structures taller than the sampler closer than 5 m;
- (e) No object within a distance of 2.5 times the height by which the object extends above the sampler. Particular attention should be given to overhead wires used as power source for automatic collectors;
- (f) If a generator is used for power, location of the exhaust should be as far as possible downwind from the collector;
- (g) Collector intake should be at least 1 m above the ground cover to minimize collection of coarse material and splashes.

XIII-4.4.3 Types of atmospheric deposition which should be sampled are rain, snow and dry deposition. Dry deposition should be collected between wet and frozen precipitation events such as rainfall and snowstorms.

XIII-4.4.4 Automated two-bucket samplers should be used.

NOTES:

- (a) These samplers collect dry deposition in one bucket with the second bucket covered and have a sensor which detects a precipitation event and shifts the cover from the second to the first bucket during the event.

- (b) The minimum rainfall,  $r$  in mm, which can be analysed as an event for a given collector system with a collecting surface area  $a$  (in  $m^2$ ) can be calculated from:

$$r = \frac{d}{a c i}$$

where:

- $d$  is the detection limit of the instrument used for analysis, in nanograms (ng);
- $c$  is the expected concentration in the rain, ice or snow fall, in ng/l;
- $i$  is the injection factor, i.e. the fraction of the total sample injected in the instrument for analysis. For example, if the total volume of the sample after concentration is 100 ml and 20 ml is injected in the gas chromatograph, say, then  $i = 20/100$ . If the sample is analysed by atomic absorption by aspiration from the 100 ml sample, then  $i = 1$ .

#### XIII-4.5 Sampling of sediment

NOTES:

- (a) Detailed guidance on sediment sampling is given in the *Manual on Operational Methods for the Measurement of Sediment Transport* (WMO-No. 686).
- (b) Sediment can be classified as:
  - (i) Suspended material — material maintained in the water column above the bed;
  - (ii) Bed-load or traction-load — material found in almost constant contact with the river bed, but moved along by the flow;
  - (iii) Deposited material — material allowed to settle out by a decrease in water energy, characteristically fine on lake bottoms and more heterogeneous on river beds.
- (c) Where suspended sediment concentrations are high, grab or depth-integrating water samplers may be adequate. However, to obtain a sample of 5 g, it may be necessary to treat thousands of litres, necessitating pumping systems, preferably with a continuous flow centrifuge to avoid laborious filtration procedures.

Bottom sediments are conveniently sampled by use of a dredge such as the Shipek sampler or the Birge-Ekman dredge, although gravity or piston core samplers should be used where less disturbed samples are required. If the interstitial water is anoxic, to undertake any study it should be preserved under an inert atmosphere.

#### XIII-4.6 Groundwater

XIII-4.6.1 In addition to the station information required under XIII-3.6, the well used should be further described by providing:

- (a) The aquifers tapped;
- (b) The well depth, size, type of casing, and location and type of perforations in the casing;
- (c) A survey including the elevation of the land surface;
- (d) A diagram and photograph of the well, showing access to it and the measuring point;

- (e) The local name of the well, and its owner's name;
- (f) The use of the well.

XIII-4.6.2 The water level should be measured, using either a weighted steel measuring tape rubbed at the lower end with blue carpenter's chalk to show the water level, or a tape detecting the water level by its electrical conductivity, or a bubbling air line converting the pressure required for bubbling into the depth of submersion to be subtracted from the total length of the line. Recording devices employing floats, electrical devices and pressure gauges can be used to monitor changes in water levels.

XIII-4.6.3 Samples should be taken from pumping wells or from capped artesian wells. In open wells and where samples from specific depths are required grab samplers, of small external diameter for narrow well casings, should be used.

XIII-4.6.4 Soil water samples from above the water table should be taken by driving tubes with a porous region near the bottom into the soil, or by embedding porous ceramic cups in the ground supplied with vacuum lines.

### XIII-4.7 **Samples for radioactivity measurement**

XIII-4.7.1 Precautions should be taken to avoid adsorption on the walls of the container or on suspended matter.

NOTE: Acceptable container materials include polypropylene, polyethylene or Teflon.

XIII-4.7.2 To keep metals in solution and minimize their adsorption, hydrochloric or nitric acid, 2 ml/l of sample, should be added.

### XIII-4.8 **Shipping of samples**

When shipping samples to the laboratory for analysis, each sample should be labelled with full information on the station, date, time, parameters to be analysed, methods of preservation if any, and the identity of the collector, together with an optional narrative description to identify any special circumstances affecting the interpretation of the data.

NOTE: Depending on local rules of evidence, any sample which may form part of the evidence in legal proceedings may require the maintenance of a verifiable chain of custody through all persons having custody of the sample from the collector to the analyst.

## XIII-5 **Quality assurance**

### XIII-5.1 **Generalities**

NOTES:

- (a) Quality assurance consists of quality control, the overall system of guidelines and procedures designed to control the

quality of the product, and quality assessment, the overall system of activities which ensure that quality control is being effectively performed.

- (b) Analytical methods can be classified as:
  - (i) Primary methods, suitable for establishing the analytical data for standard reference material; exacting, time-consuming and requiring a high degree of skill;
  - (ii) Routine methods, suitable for day-to-day use with numerous samples, for good precision and accuracy.
- (c) Accuracy of routine methods can be checked by the use of samples of known concentration, such as standard reference materials, and by the addition of known amounts of "spikes" to the sample being analysed.

XIII-5.1.1 The quality assurance programme shall include documentation of field and laboratory protocols.

NOTES:

- (a) Quality of analytical results is defined by their precision, a measure of the closeness of agreement between data generated by replicate measurements, and accuracy, the degree of agreement of the data with the "true value".
- (b) The precision measures the variability of the method resulting from random errors, and is generally reported as the standard deviation or the relative standard deviation of a series of replicate analyses.
- (c) Accuracy is usually expressed in the form of % error, i.e. 100 times the difference between the mean value obtained and the true value, divided by the true value.
- (d) The accuracy of a method can be determined by analysing standard reference materials or by the addition of known amounts of "spikes", analysing them, and determining the % recovery. This measures the capability of the method to recover known amounts of material added to a sample.

XIII-5.1.2 For each method and for each instrument in a laboratory the following values should be determined:

- (a) Instrument detection limit — the lowest concentration of analyte that an instrument can detect which is statistically different from the instrumental background noise;
- (b) Method detection limit — the lowest concentration that a method can reliably detect which is statistically different from the value obtained from a blank, e.g. distilled water, carried through the same method;
- (c) Practical detection limit — the lowest concentration that a method can reliably detect in a real sample-matrix which is statistically different from a blank carried through the method on the same sample-matrix;
- (d) Limit of quantitation — a value of a sufficient number of standard deviations, usually above the average value of the blank, that not only indicates the presence of the analyte detected, but is also a useful value for the concentration determined.

## NOTES:

- (a) Sampler blanks — samples consisting of ultra-pure distilled water poured into or permitted to pass through the sampler and run through the rest of the field and analytical process, including field preservation and transportation to the laboratory.
- (b) Bottle blanks — samples prepared from ultra-pure water or a solvent placed in randomly selected sample containers and run through the analytical process to ensure that no contamination is introduced through the bottle-washing process.
- (c) Field blanks — samples prepared as the bottle blanks, but also adding the chemicals required to preserve the sample until it is analysed. These samples detect any contamination due to the chemical preservation of samples.
- (d) Filter blanks — samples prepared from ultra-pure water which was passed through the field filtering apparatus. These samples are used to detect contamination occurring during field filtration.
- (e) Duplicate samples (splits) — subsamples obtained by dividing a sample in two or more parts.
- (f) Replicate samples (temporal) — samples taken at the same location at specified, usually short, time intervals.
- (g) Spiked samples (standard additions) — split samples spiked with several different levels of the parameters of interest, to detect the introduction of systematic errors or bias into the analytical method.

**XIII-5.2 Quality assessment reports**

XIII-5.2.1 Quality assessment reports should be required from each level of laboratory supervision, from bench analyst to section head.

XIII-5.2.2 The bench analyst should report:

- (a) The variability of data for blanks and standards;
- (b) The precision and accuracy of groups of tests;
- (c) The number and type of quality control analyses whose results deviated by more than a preset amount, e.g. two standard deviations, from the true values;
- (d) Other information relevant to quality control, such as: variation in standard solutions, reagents found to be substandard, methods used in housecleaning, samples with incorrect or inadequate information, frequency of instrument calibration.

XIII-5.2.3 Laboratory supervisors should report, appropriate to the supervisory level:

- (a) Frequency of user/client complaints;
- (b) Training sessions attended by staff;
- (c) Analytical audits and checks of data against historical values;
- (d) Interlaboratory quality control studies in which the laboratory participated;

- (e) New analytical procedures introduced or modified;
- (f) Overall precision and accuracy of group results;
- (g) Other information relevant to quality control, such as: incidence of instrumental breakdown, frequency of data verification.

**XIII-5.3 Data recording**

XIII-5.3.1 In no case should a value of zero be recorded for an analytical result.

NOTE: If the value obtained is below the method detection limit, it should be recorded as such, e.g. "less than [state the method detection limit]".

XIII-5.3.2 Values below the practical detection limit or the limit of quantitation should be so identified, in the latter case normally by enclosing the data in parentheses.

XIII-5.3.3 Quantitative data should be accompanied by measures of precision and accuracy where available, and by expected reliability such as the confidence interval.

NOTE: A confidence interval is a statistically-derived estimate that the true value lies in a given percentage of determinations between the stated upper and lower limits about the sample mean value as determined.

**XIII-6 Field safety****XIII-6.1 Training**

XIII-6.1.1 Field personnel should receive the necessary training to become knowledgeable of the hazards they may encounter, to recognize potential hazardous situations, and to take measures to minimize hazards.

XIII-6.1.2 Training should include water safety, field first aid, wilderness survival and basic methods for repairing transportation vehicles.

XIII-6.1.3 Field offices should maintain a current list of relevant safety courses available from government or private agencies, together with a record of courses taken by their personnel.

XIII-6.1.4 Periodic refresher courses should be organized.

**XIII-6.2 General practices**

XIII-6.2.1 All employees should be aware of, and adhere to, safety procedures promulgated by their governments.

XIII-6.2.2 Field staff should be provided with available information on the characteristics of water bodies to be studied and weather forecasts for the area.

XIII-6.2.3 Sampling should not be carried out if abnormal weather or water conditions prevail which are considered to be hazardous to the safety or the health of staff members or likely to damage equipment.

XIII-6.2.4 Field parties should leave accurate sampling schedules and expected itineraries in the field office.

### XIII-6.3 Safety precautions when sampling

XIII-6.3.1 Each type of sampling site requires its own set of safety precautions. Field personnel should consider:

- (a) Highway bridges — the need for warning lights, signs, fluorescent clothing, flags on equipment suspension lines, presence of power lines;
- (b) Railway bridges — knowledge of train schedules, have equipment that can be moved quickly;
- (c) Wading — be aware of insecure banks, slippery rocks, fast-flowing water, have available rod for probing depths, flotation device (e.g. life jacket), safety line attached to a rigid mooring, knowledge of quicksand procedures, have change of clothing to avoid wet clothing hypothermia;
- (d) Boats — need for compliance with local small vessel regulations, avoidance of busy navigation lanes, at least two persons present, auxiliary power for emergencies, extra fuel and spare parts, no overloading, flotation devices, clothing to avoid sunstroke or wet clothing hypothermia, avoid floating or submerged debris.

XIII-6.3.2 Field personnel should be trained to recognize potential hazardous situations and to take necessary measures to minimize hazards. In addition to physical site hazards, water being sampled may contain chemical and/or biological substances which may be harmful and contact with the skin should be avoided. Special precautions will be required in the handling of sewerage and industrial effluents.

### XIII-6.4 Handling chemicals and equipment

XIII-6.4.1 Acids and bases should be stored and handled with care, and never pipetted orally. Safety glasses should be worn at all times when handling acids and bases. Spills should be cleaned up immediately by flushing with large quantities of water or neutralization; gloves and an apron should be included for such clean-up operations.

XIII-6.4.2 Inhalation of vapours or direct contact with skin, eyes and clothing should be avoided. Skin which has been in contact with an acid or base should be washed immediately with plenty of water, followed by washing with soap or swabbing gently with a neutralizing solution.

XIII-6.4.3 Chemicals in eyes must be flushed immediately with water, having the eyelids held open if necessary. All eye injuries should receive professional treatment as soon as possible.

XIII-6.4.4 Use of mercuric chloride (corrosive sublimate) should be avoided unless absolutely necessary. If it is used, operators should have specific hazards training and all mercury residues should be recovered.

XIII-6.4.5 Work procedures should be designed to minimize the electrocution hazards of working with electrical equipment in or near water. Electrical equipment should never be directly wired to power lines without plugs or switches for quick and easy disconnection.

XIII-6.4.6 Self-contained underwater breathing apparatus (scuba gear) or other diving gear should always be checked before use to ensure reliability.

